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ispiece, No. 2.

ELECTRIC LIGHT INSTALLATIONS.
—
VOLUME I
—
THE
MANAGEMENT OF ACCUMULATORS.

A Practical Handbook

BY

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FELLOW OF THE CHEMICAL SOCIETY.

ETC., ETC., ETC.

SEVENTH EDITION, REVISED AND ENLARGED.

WITH ILLUSTRATIONS.

*An Edition, mostly re-written, of "Electric Light Installations and the
Management of Accumulators."*

LONDON:

WHITTAKER & CO., WHITE HART STREET, E.C.

GEORGE BELL & SONS, YORK STREET, COVENT GARDEN.

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PREFACE TO THE SEVENTH EDITION.

THIS little book aims at filling a gap which, in practical scientific literature, is very noticeable. It presents to the reader a general survey of the practice of Electric Lighting and Management of Accumulators, with such recommendations as are likely to assist him in obtaining successful results. The former editions were so rapidly disposed of that it was evident a demand for such a work existed in this country, as well as abroad, since it has been translated into the German and French languages.

A seventh edition having been called for, the opportunity has been taken of thoroughly revising and greatly enlarging the work—a very considerable portion having been re-written. On account of the increasing size of the book, the present edition is divided into three volumes—Vol. I., Accumulators; Vol. II., Machinery and Apparatus; Vol. III., Practice. The introduction of many new plates will, it is hoped, render the text more intelligible to the reader, and familiarise

the eye with the manufactures of different makers, thus meeting what appears to be one of the requirements at the present moment.

No other book has yet been written on the special subject of the management of an accumulator—a circumstance which has created some surprise, although, on examination, the reasons become clear enough. Two classes of persons are interested in batteries—namely, the manufacturer and the purchaser. The former, as a rule, knows comparatively little of the properties of batteries, for his knowledge is confined to laboratory tests, and it is not to his interest to publish all the shortcomings of his wares. On the other hand, the true knowledge of how a battery will act is gained only by experience extending over a long period, during which the accumulator is almost invariably in the hands of an unprofessional user, who seldom knows sufficient to enable him to examine the question for himself. Therefore, the privilege remains with a very few to observe, scientifically as well as practically, the working of batteries; and out of this limited class not many have the time or opportunity to write on the subject. The author has attempted to fill this blank which lies between the manufacturer of cells and the general user, and he trusts that benefits will accrue to both from the perusal of these pages.

The writer feels confident that the directions here laid

down, if carefully followed, will prove of great service, so that professional advice may very rarely be required. In fact, this little book is the outcome of years of labour and of an almost countless number of experiments, undertaken without considering trouble or cost; for solely in this manner can reliable results be obtained. Only those types of cells largely in practical use are dealt with. The many other types that exist would be more properly described in a history on the subject which this little treatise is not intended to be.

It is possible that some of the types, existing at this moment more or less in an experimental form, may prove to be superior to those now in general use; but experience is as yet insufficient to show which these are.

The Introductory Chapter is practically a reproduction of an article contributed by the author of this work to "Lippincott's Magazine," and which, by the kind permission of the editor, he is now able to submit to his readers. The object of its insertion here is to afford an opportunity of presenting an elementary view of electric lighting to those who may seek it.

Since the issue of the last edition many well-known companies have appeared under new names, which are already familiar to the public. Many types of cells and many pieces of apparatus have likewise been relegated to the past. It is, therefore, proposed to refer to firms and to state facts as they now are, leaving readers who

may desire to know ancient history to consult the earlier editions of this book.

Professor Ayrton read an important paper on secondary batteries before the Institution of Electrical Engineers when they met at Edinburgh in the summer of 1890, and in the autumn of that year a discussion took place in London. The author, therefore, in revising this work has been much assisted by the experiences expressed on those two occasions by Professor Ayrton and other electricians.

To friends and correspondents, as well as to his former tutor Mr. B. Loewe, F.R.A.S. (who died last year regretted by all who knew him), the author is much indebted for so many valuable suggestions that have materially assisted him in his difficult task.

His thanks are also due to the numerous firms who have kindly lent the blocks from which most of the plates in this book were printed. The presence of these illustrations will prove of great advantage to readers, so that their gratitude must be added to that of the author.

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INDEX OF TERMS

H_2O = Water.

H_2SO_4 = Sulphuric acid.

PbO_2 = Lead peroxide.

PbO = Lead oxide.

H = Hydrogen.

O = Oxygen.

Pb = Lead.

E.M.F. = Electro-motive force, or pressure of current.

Ampère = Unit of measure for quantity of current.

Volt = Unit of measure for pressure of current.

Watt = Volt $\times$ Ampère = Unit of measure for electric energy.

Electrolyte = The liquid put in a cell.

s.g. = Specific gravity.

c.p. = Candle-power.

THE MANAGEMENT OF ACCUMULATORS.

INTRODUCTION.

THE object of this chapter is to place before the reader a general view, expressed in a simple way, of electric lighting. This may prove convenient to many persons who may not feel disposed to peruse the whole book, but may have obtained it for purposes of reference. Most of the points mentioned in this introduction will, therefore, be found treated in a more complete manner in succeeding chapters.

To bring to the understanding of the general reader how the electric light is produced is no easy matter. (By "general reader" is meant a person whose scientific knowledge is of the most elementary character.) The following description is an attempt in this direction. In order that the untrained mind may realise natural laws and phenomena which are either unknown or unfamiliar to it, comparisons have to be made between them and the phenomena which are within its knowledge. This is not a strictly scientific method of proceeding, and, when employed in the present chapter, any comparisons given must be restricted merely to the statement made; there must be no further deductions, whether such deductions are right or wrong.

Practical electricity is the application of a certain known form of energy to practical ends, such as telegraphy, telephony, lighting, motive power, welding, chemical operations, medicine, and an infinite number of other purposes. The subject to be treated here will be that of lighting and motive power only. This divides itself into three parts: (1) The production of the energy, *i.e.*, electric energy; (2) the means of conveying that energy to the point or points where it is to be used; and (3) the apparatus for giving the desired results.

Although there are various ways of producing electricity, from the rubbing of a piece of sealing-wax on the coat-sleeve to the vast engines employed at large central lighting stations, yet here will be considered only such methods of obtaining the force as are in practical use on a moderate scale.

The current for electric lighting may be produced either from chemical batteries or from machines termed dynamos. Thermo-electric machines also exist, but so far they have taken no place of practical importance. The dynamo is an apparatus, a portion of which has to be revolved in order to produce a current, and consequently requires some motive power, which is obtained from a steam-engine or some other source. The fact must be remembered that a steam-engine derives its power from the fuel in the boiler furnace, or from gas, petroleum, or some other material, being consumed—to use a common phrase—for in reality it is simply the material passing from one chemical state to another, no actual consumption taking place at all. It will thus be seen that the power obtained from all engines is in the first instance, by a chemical process, and therefore, comparable with a complex chemical

battery. It might be thought that, when the current is produced by water-power, chemical action is no longer the source of current-production; but this is not necessarily so, for the water, whence the power is derived, has been raised from low levels to high levels; this raising having been accomplished by the sun's heat, which may be due to chemical action. The water was raised from low levels in the form of vapour, and deposited at higher ones in the form of rain. Therefore, it might be assumed that, electricity can probably be produced only by chemical action, and that, whenever any chemical action takes place, electricity is produced; and in our world the chemical hypothesis is probably true. Even the electricity obtained by rubbing sealing-wax is derived from chemical action in the human body. As to whether the sun's heat is due to chemical action taking place at its surface or not, that is a question still occupying the attention of scientific men; because it is doubtful whether, at the high temperatures known to exist there, chemical action is possible at the present time. Should this prove to be the case, then the sun's heat may result from some antecedent atomic or molecular motion of matter produced by the action of chemical affinity, or by mechanical motion of some kind, which may, in its turn, have been originated by heat, gravity, or other undiscovered cause.

However, it is usual—without entering into further refinements—to speak of the electric current as being produced either by means of an engine of some kind, water-power, or from batteries. The engines employed are usually steam or gas, and both are so familiar to everyone that to describe them is unnecessary. The apparatus revolved by the engine, and termed the

dynamo, wherein the current is actually produced (or, more strictly speaking, the apparatus in which the power derived from the engine is converted into electric energy), will claim our attention after a brief reference to batteries.

Batteries are divided into primary and secondary. The former are those wherein the materials, part or all of them, become exhausted, and at this stage fail to supply electricity, unless a portion or the whole of the materials is renewed. The secondary battery is one which becomes exhausted exactly in the same way as the primary, but the chemical contents are of such a nature that it is merely necessary to pass a current of electricity through the battery in order to restore them to their original condition. To give a practical instance: everybody is familiar with the primary cell, consisting of a pot of weak sulphuric acid, in which are immersed two plates—one of copper, one of zinc—which are not permitted to touch in the liquid, but are connected with one another outside the liquid by means of a wire of any length, the ends being joined to the plates respectively. Under these conditions the fluid bubbles like soda-water (which indicates that some of it is being converted into gas), and a current flows through the wire. This is a simple illustration of chemical and electrical action proceeding at the same time, and which, as already stated, must necessarily take place although not always self-evident.

On disconnecting one end of the wire from one of the plates the bubbling ceases, which shows that the action has been arrested. In the course of the wire an electric lamp, a motor, or an instrument for indicating the presence of a current, or any other apparatus, may have

been inserted ; and all the results so well known, which can be produced by means of an electric current, would have made themselves manifest. But, of course, no appreciable quantity of light or power would be produced from such an experimental cell ; many such cells coupled together would, to be of practical service, be needed, and the combination is termed a battery. In a short time the zinc plate in the cell is dissolved, the power of the liquid also becomes exhausted, and the production of the electric current thereupon ceases. But supposing these two plates, instead of being copper and zinc, had been one lead and the other double oxide of lead, then, although the current produced would cease to flow after a time, instead of requiring a portion of the contents of the cell to be renewed, it would only be necessary to pass through the cell a current produced from some other source in order to restore its vitality. Such a combination is termed a secondary cell ; and a number of these, suitably connected together, form a secondary battery, very commonly known under the name of an accumulator. An accumulator, therefore, is nothing more than a primary battery in which the chemicals can be renewed as often as required by merely passing a current of electricity through it, such current in practice being produced by means of an engine and a dynamo. It may also be observed that the primary battery at the present moment is not a suitable means for producing electricity on a large scale, for, apart from expense, the necessity to replace new chemicals in the cells from time to time involves considerable trouble and inconvenience, whereas to replenish an accumulator by running an engine is a very simple matter.

Turning to the dynamo, no attempt can be made here

to enter into a full description of the apparatus, which is made in an almost unlimited number of ways ; but sufficient explanation may be given of its general principle in order to show how a current is produced from it, the principle being the same in all types, no matter how the machine may be constructed.

Dynamos are of two kinds : one made to produce a continuous current, and the other an alternating current. Although these currents are very dissimilar in character, no difference is to be observed when they are employed to give light. A continuous current may be compared to a liquid wherein waves are continually progressing in one direction. The direction towards which the waves are moving is termed the positive direction, and that from which they come, the negative. Hence, if a wire with a current flowing in it be attached to a lamp in such a manner that the waves move towards the point where the wire is attached to the lamp, it would be said that this part of the lamp is attached in such a way as to receive a positive current ; and the other part where the current leaves it (since the waves will evidently move away from this part) is termed the negative. In this explanation the lamp must be regarded as a portion of the circuit, modified in such a fashion as to be capable of converting the electric energy into light. The reader will, therefore, observe that, when a positive or negative current is spoken of, it simply indicates direction. Notwithstanding this, positive electricity and negative electricity have a variety of phenomena peculiar to each.

The alternating current may be regarded as a fluid in which a wave proceeds first in one direction and then in the other, see-saw fashion ; and in practice these changes

of direction take place as frequently as from fifty to two hundred times per second.

Instruments employed for continuous currents may contain iron and permanent magnets, but for the alternating the latter must be completely absent, and any iron employed in their construction must be very soft and much subdivided, or it will become extremely hot.

The dynamo that is to produce the continuous currents consists of two parts—one stationary, and one to be revolved. In the most usual type the stationary portion consists of a powerful electro-magnet, horseshoe in shape, the free ends of the horseshoe being termed poles. These poles are so arranged as to permit the moving part, called the armature, to revolve between them. The armature consists of a spindle running in bearings, and is revolved by motive power, either by being connected directly with the engine or indirectly by means of a belt, in which latter case the spindle carries a pulley. Upon the spindle is placed a suitable framework, and wire is wound upon this in a special manner so as to form a continuous coil, which may contain (as it generally does,) or may not contain, some soft iron. When the armature is removed from a machine it has somewhat the appearance of a short bolster with a spindle pushed through. The bolster part, on close examination, will be found to consist of the coil of wire already mentioned. This wire coil portion revolves between the magnet poles. The spindle at one end carries a number of copper plates, placed radially and close together, so as to form in appearance a solid cylinder, termed the commutator. Each plate is insulated from the next and from the spindle. By

insulation is meant that some substance is placed between plate and plate, and between plates and spindle, through which the electricity will not pass. Upon this commutator rest two copper brushes, to which are attached the wires (in a shunt machine) which lead to any point where electric energy is required. Every plate in the commutator has a wire attached to it, the other end of the wire being in connection with some point of the armature coil. It will thus be seen that any current produced in the armature will travel to the copper plates, and enter the brushes which press upon them, and so pass on into the wires (generally termed cables, mains, or lines) and travel to the point required. When the armature is revolved, the plates of the commutator successively pass under the brushes, which usually consist of a group of fine copper wires, or thin plates, of considerable length to give them elasticity and to allow of their being moved forward to make up for wear and tear. In all cases the current produced by means of dynamos is alternating. Consequently, when a continuous current is wanted it must be changed from one form of current into the other. This is effected by means of the commutator, just described, as the name would appear to imply.

A portion of the current produced is employed to excite the electro-magnets. Permanent magnets may be used—in fact, they are still used in France for dynamos placed in lighthouses—but for general purposes the electro-magnets are cheaper, and have many other advantages. A piece of soft iron, wound round and round with wire, which has a current passing through it, becomes a powerful magnet; such a combination being termed an electro-magnet. Iron, under

these conditions, is said to be "excited." When the electro-magnet of the dynamo is excited, the armature is in an extremely powerful magnetic field; which means that it is strongly under magnetic influence. If the spindle is revolved subject to these conditions, and the wires leading from the brushes are connected so as to form a closed circuit with appreciable resistance, it will be found that the power required to turn the spindle with the armature increases as the speed is raised. The best comparison to make is that of turning a fan in a barrel of treacle: the quicker the fan is turned, the greater will be the resistance to its motion. The very revolving of the armature before the poles of a magnet, which, as explained, is nothing more than a specially-wound coil of wire, produces in it a current of electricity; and the faster the coil is turned, the greater the pressure of the current. The quantity of electricity produced is dependent upon the resistance of the circuit.

The resistance is made up, in the simple case imagined, of the wire in the armature, the length of which is invariable, and of the variable length of wire of the outside circuit, the ends of which are joined to the brushes. Evidently, the longer this wire is, the greater will be the resistance offered to the passage of the current; and, if the pressure were to remain unaltered for two different lengths of this wire, the quantities of current which would flow through it must necessarily vary with its length (*i.e.*, if the armature-coil resistance is not considered). The resistance of the armature coil is always very small and may practically be neglected, so that the current flowing in the system may be considered proportional to the resistance of the circuit outside the machine. In an electric-light installation

the resistance of the outside circuit would be virtually proportional to the number of lamps in use at any time, since adding or subtracting lamps increases or diminishes the resistance of this circuit.

In a well-constructed dynamo, running at a given speed and intended to produce current for a certain number of lamps, the pressure should remain constant, whether one lamp, or more, be in use upon the circuit; and this is of great importance, for otherwise the light from the lamps would vary according to the number employed. When such self-regulation cannot be obtained, electric governors secure constant pressure.

One form of alternating-current dynamo consists of a number of coils placed upon the periphery of a wheel, and which are revolved before electro-magnets excited from a small continuous-current machine such as that just described. The arrangement of the various parts permits an alternating current to be produced in the moving coils. This current is collected by means of brushes, as in the last case; but the commutator is replaced by two collecting rings of metal connected with the wire upon the moving coils, but otherwise insulated. The conditions for regular pressure and quantity of current, in the case of alternating currents, being very complex, they cannot be considered in an elementary discussion of the subject. These descriptions of the two usual types of dynamo are only of the most superficial kind, the aim being to give merely a general idea of the machines.

Having dealt with the production of the electric current, it becomes necessary to consider how it is conveyed to those points where it is required, and then to examine the apparatus used for obtaining practical results.

In order that the current may travel, the circuit must be complete. The circuit may be compared to a system of hot-water pipes, such as are used for warming hot-houses. In a hot-water system there is a boiler: a flow and a return circulating-pipe, with pipe-coils at various points for giving off heat at places where warmth is required. In an electric installation the dynamo replaces the boiler: flow and return pipes are represented by the two conducting mains, and the pipe-coils by lamps, motors, and other apparatus. In a hot-water system it is perfectly evident that whatever be the quantity of water leaving the boiler, the same must return to it, and the quantity of water passing through every part of the flow and the return pipes in a given time must be alike. It is so with the electric current: whatever may be the quantity of the current starting from the dynamo, the same quantity comes back to it. Also the whole of this quantity must pass through the mains. But it is different with the pressure: this diminishes in proportion to the work done by the current. Consequently, the pressure diminishes as the current advances on its path. Comparing this again with the hot-water system, the analogy is fairly complete; for the current may be regarded as losing heat (this is often disguised) as it advances, since in losing its pressure it produces heat, and the hot water does the same.

The passage of a current through a conductor cannot be effected without loss of power, *i.e.*, diminished pressure. Loss of power means work done. If this work has a useful purpose, it is not a loss in the common sense of the word; but in all other cases it is waste. Any pressure of the current lost in a lamp

produces a desired result. Since this is not so for the mains, the system must be constructed in such a manner that as little loss as possible shall occur in conducting the current from point to point, where practical results are needed; and that is effected by making the mains as large as possible. The size of the mains is limited only by the consideration of their cost. To sum this up, nearly the whole pressure of the current, in a well-designed installation, may be regarded as being lost in passing through the lamps, motors, and other apparatus.

It would thus seem that the larger the section of a wire the less resistance does it offer to the passage of a given current. One wire double the diameter of another will offer four times less resistance. If the current passing through any wire is doubled, the loss of pressure in travelling a given distance will be four times greater, three times the current, nine times: *i.e.*, the waste increases as the square of the current. In electric lighting, the waste invariably consists in producing heat at places in the circuit where it is not required; and if this is generated in too great a degree by reason of the mains offering too much resistance—that is, being too small in section—a fire may result. There is waste also by leakage, but this exists only to an inappreciable extent in a well-designed installation. To avoid the possibility of a fire, through overheating, the current is made to pass in its course, at suitable points, through short pieces of metal far more fusible in nature than the material of which the conductors are made. The conductors are usually of copper. The fuses, as a rule, consist of tin wire, and are generally called “safety junctions.” Then, if the current rises, from any cause, beyond a certain limit, the safety junctions

melt and cut the circuit before any damage is done. There are other devices also for cutting off the current in case of need, and they are described in a later chapter.

The only apparatus in connection with an electric-light installation that require to be considered here are the arc lamp, the incandescent lamp, the motor, the switches, the instruments for indicating the quantity and pressure of the current, and the meter.

In the arc lamp the current passes through two carbon rods, which are separated from one another by a very short distance. In order that the current shall leap this interval, the rods are made to touch one another for a moment, and then to separate. A flame, consisting of heated gases, is to be observed between these carbon rods, which must not be mistaken for visible electricity. The powerful light is produced by the intense heat to which the ends of these rods are raised. Suitable apparatus is connected with these rods in order that they may be fed as they burn away: otherwise, the distance between them will increase, and eventually the current will cease to flow.

The incandescent, or glow, lamp consists of a very fine filament of carbon, hermetically sealed in a glass globe from which the air has been exhausted. The ends of the filament reach the outside of this globe by being attached within it to two platinum wires, which pass through the glass to the outside, and there they are dealt with in some convenient way whereby they may be joined to the circuit. When so joined, the current enters the filament at one end and leaves it by the other, the filament becoming white-hot during the time that the current passes through it, but is not consumed, since there is no air present. The high resistance of the

carbon filament necessitates a great loss of pressure in the current during its passage through it, and is converted into light-giving heat. If the pressure of the current is greater than that for which the lamp was constructed, too much current will pass through the filament and it will be destroyed. On the other hand, if the pressure is insufficient, the temperature to which the filament ought to be raised will not be reached, and the light will be far less than it should be under normal conditions. The light given by any lamp diminishes in far greater proportion than the equivalent fall in the pressure of the current; and the inverse is true. For instance, a lamp intended to give a certain light with a given pressure of current would yield less than half its light with a fall of 10 per cent. in pressure. On the other hand, a 5 per cent. increase of pressure above the normal would produce at least double the light for which the lamp was made.

A motor is identical with the dynamo. In the latter case the armature is revolved and a current produced, but when a current is sent into a dynamo, the armature revolves—in other words, it becomes a motor. Here is presented, perhaps, the simplest way of conveying power that has ever been discovered. If a lathe or other machine has to be turned by power at any given place, it will be necessary merely to convey to that place two wires for conducting the current and a motor to be attached to them. Though heavy, a motor is compact; and a man can, on a properly-designed truck, move about without difficulty from place to place such a machine up to the size, say, of a 10-horsepower motor. Apart from the rapidity and ease with which motive power may be installed, wherever it is desired, there

are eliminated the dangers and complications which exist more or less in connection with the forms of motive power hitherto employed.

In order to light and put out a lamp, or start and stop a motor, the current must be cut. Simple apparatus are employed which break the metallic continuity of the circuit, this being all that is necessary. Such devices are termed switches.

Two instruments are used in order to observe what is taking place upon the circuit. The one is termed an ammeter, and indicates the quantity of current, the unit being termed an ampère. The other instrument is called a voltmeter, and registers pressure, the unit being termed a volt. There are also meters, equivalent to a gas-meter, whereby the electrical energy used over any given time is recorded.

There are two systems of distribution—one termed the series and the other the parallel. Each of these systems has many sub-divisions, also combinations; but only the simple methods need be referred to.

In the series system the conductor consists of one continuous circle. The lamps and other apparatus which are inserted form a part of such conducting ring. In this method high pressure currents have to be used, because there is a fall of pressure as the current passes through each succeeding lamp or other piece of apparatus.

The glow-lamps mostly in use require a pressure of 100 volts. As just pointed out, volt is the unit measure of pressure. Suppose, therefore, a circuit to contain 50 such lamps, 5,000 volts would be required in order that they might give their normal light. Arc lamps, whether made to give a large or a small light, need a

pressure of 50 volts to work them. Occasionally it may be a little more or a little less, according to the make of the lamp. Therefore, 50 such lamps upon a series circuit would require a current having a pressure of 2,500 volts. A pressure exceeding 500 volts with a continuous current, and 200 volts with an alternating current, may prove fatal to human life under certain conditions.

In the parallel system, which is free from danger, since high pressure is rarely employed in connection with it, the flow and the return mains may be supposed to be of equal length and laid parallel with one another. At various points along these mains branch wires start, a lamp or motor being placed in the course of each branch, so that the current in passing from one main to the other traverses the lamp or other piece of apparatus. If a diagram of this system were drawn on paper, it would have the appearance of a ladder, the lower end of the sides being connected to the dynamo and the top ends free. The rounds of the ladder would represent the connecting cross wires, each one having a lamp or any other piece of apparatus in its course. Evidently, if the resistance of the large mains represented by the sides of the ladder is very low, the current traversing the cross branches will be virtually proportional to the resistance of these branches; and for lamps made to give equal light placed in these branches, the resistances of the latter must be made approximately equal.

The resistance of the 100 volt 8-candlepower glow-lamp, most commonly in use at the present time, is about 300 times greater than that of the mains and branches leading to it. Consequently, if the flow and the return wire of such a lamp were to come in contact before reaching it, what is termed a "short circuit"

would result, since the electric current, like steam and water, will flow in the direction of least resistance. In the case imagined the current would pass from one main to the other with practically no current travelling through the lamp. In this event the wires leading to the lamp will pass 150 times more current than was intended, which would raise these wires to a white heat, or even fuse them if no safety fuse is inserted in the circuit. If a safety fuse does exist, the fusible wire will melt and no mischief be done.

In practice, 1-horse power will produce 1,000-candle power in an arc light; but an increase in the horse-power gives a far larger corresponding increase of light. For instance, 7-horse power will produce as great a light as 15,000 candles or more. But, on the other hand, the light given by the incandescent lamp is directly proportional to the power of production; and 1-horse power will incandesce about 16 or 18·8-candle-power lamps.

It may be interesting for the reader to learn three remarkable points which, although they have not been absolutely proved, theory and experiment go far towards confirming; and there is every probability that the great minds which are now working at the subject may before long arrive at some definite conclusion: (1) That solids are nothing more than ether vortices. (Ether is supposed to be an all-pervading medium, more subtle than any known gas, and vortex means a rapid spiral rotation.) (2) That light is one form of electricity, there being many laws in common to each, and especially as to the time occupied in passing from point to point, (3) That a current of electricity does not travel inside a conductor at all, but along the insulating

substance which surrounds it by means of the ether, the conductor itself simply acting as a director, which it may enter more or less under certain conditions. The unscientific mind may better understand the meaning of the word "director" by an analogy, which, though not absolutely true, fairly gives the idea. A water-pipe may be regarded as a director for the water, *i.e.*, the water is kept within bounds to be conveyed from one point to another, and yet does not travel in the iron of the water-pipe itself. But in the case of the electric conductor, difficult as it may be to conceive at first sight, the current flows outside it.

Although electricity was known to the ancient Greeks, the uses to which it might be applied have remained unknown for thousands of years. It was reserved to Ampère, Ohm, Volta, and Faraday, with a few others, to discover the laws which govern this force. The development of the science in its application to the practical needs of human life may be considered to date from the time of Faraday, whose career ended in 1867. In the past forty years electric science has advanced in a degree probably unequalled by the progress of any other knowledge since the commencement of the world's history. The electric telegraph was discovered about fifty years ago. The transmission of messages across the ocean dates so recently as to be within the memory of persons who can look back thirty years. The electric light can only be considered to have entered the practical stage since 1880; and although the advances during the last few years have been great, still we know that greater achievements are in store for the present and for coming generations.

It would be possible to speculate to an unlimited degree as to the future of Science, but experience shows that the knowledge of to-day is as nothing compared with that of to-morrow. A few new facts often upset pet theories. We cannot but be reminded of the words spoken by one of the greatest of philosophers that ever lived—Sir Isaac Newton—who is reported to have said, when dying, "I seem only like a boy playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me."

VOLUME I.



ACCUMULATORS.

ACCUMULATORS.

CHAPTER I.

DESCRIPTION OF CELLS AND THEIR MODE OF EMPLOYMENT.

THIS is intended to be a practical work, and therefore no attempt is made at literary style. The object of the book is simply to place before the reader a plain and straightforward statement of facts ; to treat the whole matter in as concise and clear a manner as possible, and to make suggestions where improvement appears desirable. Without further introduction, the reader will now be invited to consider the subject in what seems to be the natural order. Its treatment proceeds on the assumption that the reader of this little book has a general knowledge of electric lighting, and, consequently, minute details are not given here.

A cell, in its true sense, is the receptacle for the liquid and plates ; but, generally, the word is employed to signify the vessel with contents complete, unless by the context the contrary be indicated. A number of cells connected together form a battery ; and this, when a secondary one, is generally termed an accumulator. In order to obtain the positive and negative elements every cell must contain two or more plates. All those of the

same denomination in a cell are metallically joined together, but the dissimilar plates are not in contact one with the other inside the cell nor outside when the cell is not in use. The current inside the cell passes from plate to plate through the electrolyte, and outside by joining one set of plates to the other through a conductor, which may be very complex ; such, for example, as a long length of wire, with one or more lamps in its course. In this condition, the circuit is said to be closed ; and if the plates are not exhausted, a current flows. When the outside conductor is broken, no current passes ; and the circuit is open. The only object in employing a number of plates of each kind, instead of one positive and one negative, is to obtain a low internal resistance without the inconvenience of using very large single plates.

Cells are of two kinds—primary and secondary. The primary cells are made in as many ways as there are stars in the sky, but all have one characteristic, namely—that when exhausted the whole or part of the chemicals employed must be renewed, and in most cases the plates also. For practical electric-lighting purposes such cells are of no value, notwithstanding the assertion of many makers to the contrary. It must not, however, be supposed that a good primary battery may not one day be forthcoming, for it is quite within the bounds of possibility.

The other cells are termed secondary, because they may, without the putting in of fresh chemicals, be revived by simply passing a current through them. These have been very appropriately termed by Mr. Fitzgerald reversible cells.

Until the introduction of secondary batteries the

Bunsen battery was almost exclusively employed for obtaining large currents; but it never did, and never could have, become a battery for popular use, because of the corrosive nature of the chemicals, the poisonous fumes given off when a current was taken, and the necessity for continual replenishment. For the telegraph, domestic use, electric bells, laboratory testing, and many other purposes, the Leclanché cell has been used to a vast extent, chiefly on account of the harmless chemicals employed and the long periods of time during which the cell would work without being re-charged. The Leclanché cell may be regarded as having been completely superseded by the dry cells, which, although not new, have recently been subjected to great improvements, the Gaussner cell having led the way, so that they may no longer be classed with toys.

There are now two other excellent dry cells in the market: one supplied by the Electric Construction Corporation, and known as the E. C. C. dry cell; and the other (which is supplied by Messrs. Siemens) called after the inventor, the Hellesen cell. This latter is shown in Fig. 1. All dry cells should have vent-holes,

These dry cells are, when exhausted, capable of being restored by passing a current through them. Thus they are placed in the same category with the secondary batteries, and since they contain no liquid they are clean in use and are not liable to the many disadvantages well known to exist in cells that contain fluid. Besides these advantages, dry cells possess all that can be claimed for the Leclanché cell, and may readily be employed in connection with small lamps, for night lights and the like.

It may, therefore, be concluded that one of the great advances of the present day has been the discovery of batteries that are reversible and free from the many objections so common in older forms for large currents as well as for small.



Fig. 1.—Helleesen's Dry Cell. Siemens Bros. & Co.

It has become a practice amongst makers of secondary batteries to call the true positives the negative plates and *vice versa*. Therefore, not to cause confusion, the manufacturers' designations will be adhered to throughout this book. And it may be further remarked that scientific men have generally adhered to this rule.

The cells proper are made of glass or metal, and frequently of wood lined with glass, pitch, or celluloid. For stationary work, glass is by far the best; but for movable batteries, such as are used in launches and tramcars, other materials must be chosen.

The fluids, or electrolytes, are very numerous. They may be alkaline, acid, or neutral, according to the plates employed and other considerations.

The plates may be all metallic, or one set may be of metal and the other of carbon, or any suitable substance. In some cases neither one nor the other is composed of metal.

To attempt a description of every existing secondary cell would be of little interest in a book written solely for practical purposes, since there are but two sorts of cells which are of real value at the present time. In the one, the plates are composed of spongy or of granular lead; and in the other, the lead plates (or some alloy of lead) are perforated, and the holes are filled with lead compounds. Of both types numerous modifications are employed to obtain the same end. There is a third type, where lead plates are used in conjunction with zinc ones, the latter taking the place of the negatives; but such cells cannot be reversed an indefinite number of times, owing to the fact that the zinc plates do not, at each reversal, retain their original form, and owing also to the growth of zinc-trees and local action. They must, therefore, be excluded for electric-lighting purposes on a large scale. These cells, however, are useful for portable lamps and laboratory work, being of comparatively light weight for the energy they contain. Thus there are two types which require to be considered and described.

Those who are anxious to study other kinds of cells should refer to Mr. Berly's translation of M. Emile Reynier's treatise on "Accumulators," published by Messrs. Spon & Co., of London.

Cells of the plain lead type were shown to be reversible first by Planté, although earlier workers are said to have previously discovered this property. To Faure appears to belong the merit of having so modified the Planté cell as to make it a practical one; in fact, those now so largely used are but Faure cells improved.

There has been considerable discussion as to whether there are any patent rights existing in pasted plates in other words, whether Faure was, or was not, the discoverer and patentee of this method of making plates. It is not proposed to discuss the legal question here, but it may be of interest to many readers to know that Mr. Pulvermacher, in a patent specification, No. 2062 (1869), used these words: "Another part of my invention consists in employing negative plates of open-work form, as described so as to form constant elements by means of insoluble metallic salts capable of electrolysis and of depolarising action on the negative part of the elements, such as sulphate of lead, bi-sulphate of mercury, or chloride of silver." The claim relating to the above is as follows: "13th.—The employment of metallic salts, as before described, in plates or cores, in a way adherent to the metallic surfaces." The negative plates spoken of in the above are those now termed positive. This patent was taken out also in the United States. It would therefore appear that Pulvermacher anticipated all the present patents.

The chief aim of all improvements in the lead-plate type is to make the plates porous, yet strong

so as to offer as large a surface as possible to the electrolyte.

The second, or perforated, type may be termed pasted plates. The holes are filled with paste made by mixing red lead with sulphuric acid for the positive, thus forming lead sulphate, the negative paste being made of litharge mixed with sulphuric acid. The acid and paste frequently have a small proportion of other chemicals mixed with them to produce three results: (1) better adherence between the paste and the metal; (2) a harder paste; (3) to enable a more rapid formation.

In cells of this kind, those of the Planté type (as well as in cases where zinc plates are used to replace the negatives), dilute sulphuric acid is employed for the electrolyte.

The chemical action is the same for both types of plates, and may be explained generally by saying that when the cells are charged, more oxygen exists in the positive, and probably more hydrogen in the negative plates, than when discharged. Without giving a detailed account, a few words on the subject of their manufacture may prove of interest.

First, let us take those of the Planté type. There are many makers of this kind of cell, each of whom has a different method of rendering the lead plates porous. Some cast them porous to start with, others build them up of lead ribbon, and most treat the plates with nitric acid before they are formed. In all cases the same end is in view, viz., porosity. The positive and negative plates are identical before they are placed in the cells. They have tail-pieces (termed by the manufacturers "lugs"), either cast on them or put on afterwards, for

the purpose of connecting the plates together. A strip of lead is then soldered to the lugs of all the positives, and the same is done with the negatives destined for one cell. The two sets of plates are pushed into one another, so that the positive and negative alternate, thus forming a compact block, every plate being insulated from the next one by some non-conductor, called a separator; but each set remains joined by the lead strips described above. Such a block of plates is then firmly held together by rubber bands; or by wooden frames, the wood having been boiled in paraffin wax; or by the more recent method of strips of ebonite, vulcanite, or glass; and frequently nothing is employed. The whole is termed a "section," which is then ready for "forming." This process consists in passing an electric current, for a long period, through the cell. In practice a large number are coupled together in series to undergo the process. The result is that, though positive and negative plates are identical, after a time their chemical composition is so altered that their similarity no longer exists, and they become capable of retaining a charge: which means, scientifically, that a good primary battery is made with reversible properties. In order that a good retaining charge may be obtained in some types frequent reversals are necessary. So many improvements have been made in these plates that any reversals which may be required are now done at the manufacturer's works, so that this troublesome process need not be performed after the battery is erected on the spot where it is to be used. The reversal is accomplished by completely discharging the cells through a resistance. They are then charged the reverse way; and, to complete the operation, another

discharge must be given, followed by a re-charge in the original direction.

One point in favour of the plain lead type of plate is that a very large charging current, or rapid discharge, does not appear to injure the plates, which is the case with the pasted type. Such a battery is, therefore, very suitable for regulating the light and for short heavy

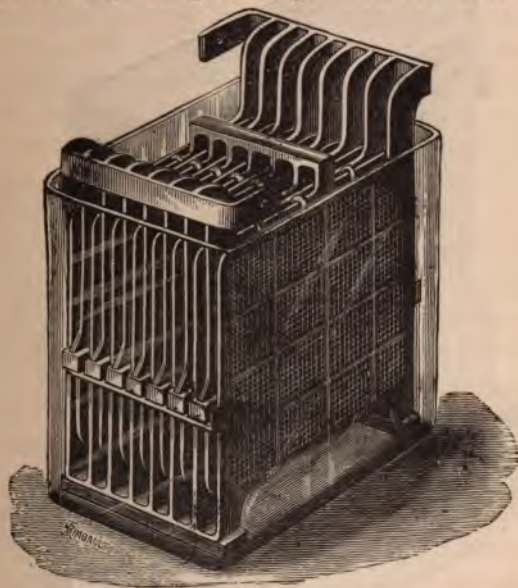


Fig. 2.—E. P. S. Cell, 1888 type (15 plate), glass cell.

discharges. It, therefore, has been introduced into many public electric supply stations, and is gradually coming into favour with private users.

A few years ago, Messrs. Elwell-Parker supplied many batteries of this type, but soon abandoned their manufacture in favour of the pasted kind. Plain lead plate batteries were also employed in the experimental

lighting of the town of Colchester (the plates being built up with lead ribbon), which attempt ended in failure. The company is no longer in existence.

The plain lead type of plate has been so largely

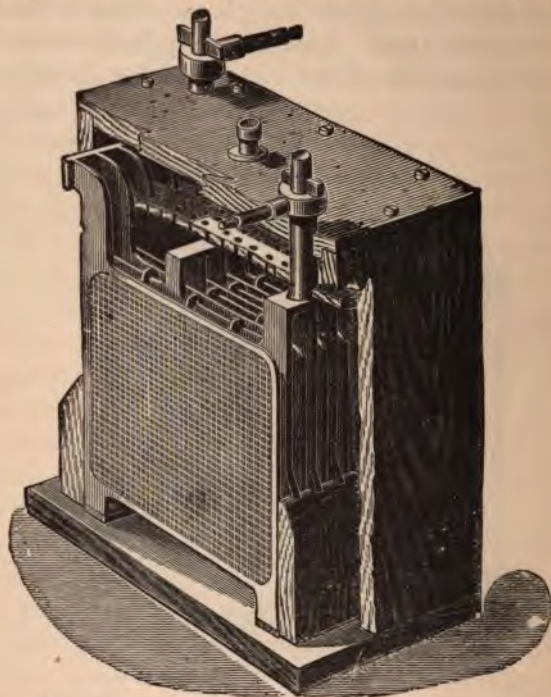


Fig 3.—E. P. S. Cell. Portable form (15 plate).

improved that the majority of the failings which attended the earlier forms have now disappeared.

At the present moment there are many makers of the Planté type of cell. Probably the largest number is turned out by Messrs. Crompton-Howell, who have adopted the process of manufacture patented by Messrs.

Williams & Howell, of Llanelly, and they are manufactured in Wales. Up to the middle of the year 1891 they had produced over 200,000 plates. Messrs. Johnson & Phillips make plates of a somewhat similar kind. There are also the plates of Dr. Frankland, which do not seem to be much used. Numerous other makers produce these plates on a small scale.

The second type, although requiring more care and attention, is still chiefly in use, but their field has been much encroached upon by other new types. This is because unpasted plates until recently were not satisfactory. It is probable that, in time to come, the Planté plate will be as largely used as the pasted plate, or may even supersede it.

The rules which should be followed for keeping an accumulator in good order apply equally to every type of cell now made. This should not be forgotten when reading all that follows on this subject, remembering, however, that since the pasted plate is more delicate extra precautions require to be taken.

In England the pasted-plate type is made exclusively, at present, by the Electrical Power Storage Company under a licence from the Electric Construction Corporation; and the largest makers of the Planté type are Messrs. Crompton-Howell. It will, therefore, be sufficient if only these two kinds of accumulator are dealt with at length. As all other cells of a really practical kind made in this and in other countries can be classed under one of the two heads referred to, the instructions which follow can be applied to them precisely in the same way.

The life of accumulators being comparatively short, and until within a recent period exceptionally so, for want of experience in their management, it may be

fairly concluded that all the earlier forms are now extinct, and any survivor may be regarded as an exception. Therefore, to describe any make of cell that is not modern would be to enter upon a history of the sub-

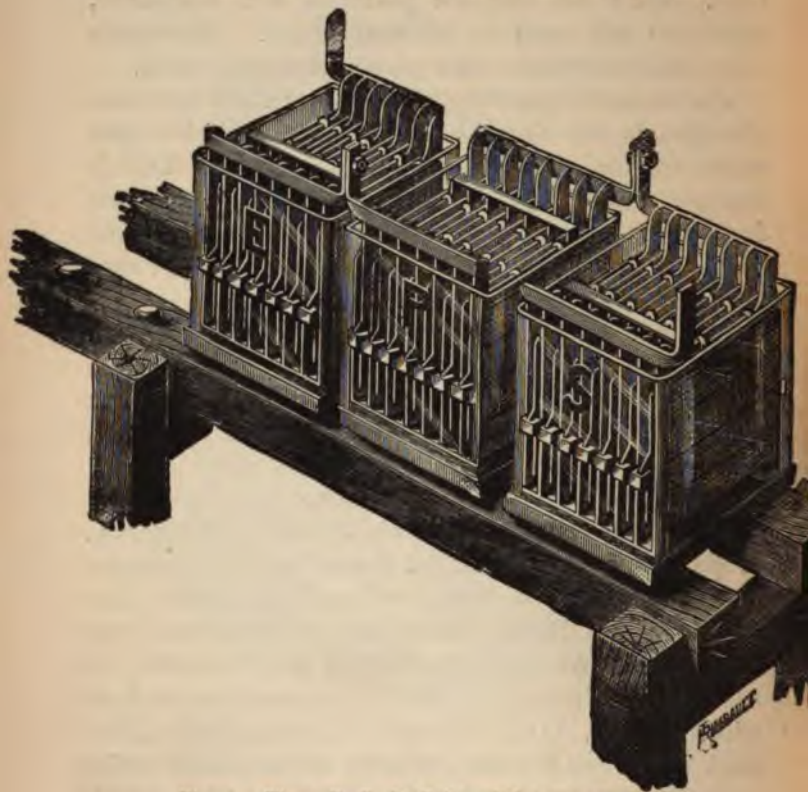


Fig. 4.—Three E. P. S. Cells, 1888 type, connected.

ject; which is not the intention of the writer of these pages.

The E. P. S. (Electrical Power Storage Co.) cell in figs 2 and 3 shows the stationary and the portable

forms. In the portable forms, it will be observed, the connecting lugs are cylindrical, the ends being conical; and over these ends are dropped thick leaden rings, to which are attached connecting wires, with conical holes, and kept in place by leaden wedges that are driven through slots in the lugs. This is an excellent way of making a good and secure contact when the cell is placed under a condition of continual vibration, as, for instance, in a tramcar. Bolts and nuts under such conditions would become loosened. Fig. 4 shows three E. P. S. cells connected together.

The Electrical Power Storage Co. also make the author's type of cell, which possesses some special advantages that will be referred to in due course.

Pasted plates are made in a variety of ways, but in all the object is to produce an efficient support (called a grid) of lead, or other suitable material, filled with a paste of a hard and durable character, and having the requisite chemical properties.

The E. P. S. grid is made of lead, or an alloy of lead, containing ten per cent. of antimony, and cast into plates covered with small square holes, pyramidal in form, with their bases on the surface of the plate, hour-glass shape in section, with a lug to which to attach the connecting strip of lead when built up into sections. (See fig. 5.) The square holes have recently been somewhat modified in details.

The alloy of lead and antimony makes a better plate, being far stronger than lead alone; and it is practically unacted upon by the electrolyte. The plates intended for positives are, as already pointed out pasted with red lead and sulphuric acid, and those to be used for negatives with litharge and sulphuric acid. In the latter

case water would answer the purpose; but the paste thus obtained would not be so coherent.

The plates are now built up into sections by soldering the lugs of a number of positives to a strip of lead. The negatives are treated in the same way. These two sets of plates are pushed into one another so that the positive and negative alternate, every plate being insulated from the adjoining one by the insertion of ebonite forks. The number of plates, of which any section should consist, depends upon the work it has to do.

The number of negative plates always exceeds the positives by one, so that a negative is seen at each end,

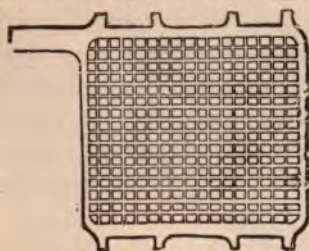


Fig. 5.—Grid.

the object being to utilise the two sides of every positive. It may, therefore, be pointed out that, if a section containing only one positive be required, a negative plate, in order to obtain the best result, should be placed on either

side of it. When the end plate is a positive, the chemical action upon its two sides is unequal, and the plate frequently buckles in consequence, which is not likely to occur with a negative plate. Of the remaining plates the edges only are visible, the plates being about a quarter of an inch apart. There is no connection between the positives except through the leaden strip at the end of the lugs, this being left long enough to join to the next cell; and the ends of the lugs, with the strip, may, or may not, remain above the liquid in the cell. These remarks also apply to the negatives. The section is now ready for forming.

The author's patented improvements, made in the year 1887, and adopted by Messrs. Elwell-Parker, were copied, in a great measure, in the 1888 type of cell of the Electrical Power Storage Company before the amalgamation of the two firms. Some of the improvements have also been taken advantage of in the K type.

The following is a detailed description of the 1888 type of cell. The negative plates are rigidly joined together by means of five lead bands, in addition to the usual connecting lead strip. These plates have also projections extending downwards at their lower corners. Two of the lead bands are joined to the extensions; they thus form flat supports for the section, one at each side of the block, and keep the plates raised from the bottom of the cell. Two leaden strips are attached half-way up the plates, one at each side, and these bands support the positives by means of special lugs or projections, insulation being secured by means of ebonite saddles. The upper ends of the negatives have small projecting lugs, which are connected together by the fifth leaden band. Ebonite forks are inserted between the plates to prevent the possibility of the latter shifting and touching one another. The plates are placed farther apart, in order that any plug of paste falling out of the grid may drop to the bottom of the pot, instead of sticking between the plates. It will be observed that the peculiar form given to the lower ends of the negative plates enables the section to be considerably raised above the bottom of the cell, thus avoiding the danger of partial or complete short-circuiting, which might arise from any deposit. The section does not rest directly upon the glass, but it

stands upon a small wooden frame, which has been boiled in paraffin wax. The paste also is of a harder character than the kind formerly used.

Although this form of section is a great improvement, still it has several drawbacks, and now that the Electrical Power Storage and Elwell-Parker Companies are united under the name of the Electric Construction Corporation, the author has no hesitation in stating his experience upon the 1888 type of cell. The method of building up the sections is decidedly bad, being insufficiently rigid. If the forks are not placed with absolute exactness, and every possible care taken to get the section "square" (which is no easy matter), the resistance between plate and plate is not symmetrical; and many well-known troubles occur in consequence. One set of the plates being joined to the band above the liquid also suffers a disadvantage. As the parts outside the electrolyte do not undergo the same chemical changes as the plates to which they are attached, there is a tendency for the plate to crack at the surface of the liquid where its projection rises to join this band. Plates frequently rot and break at this point, and, even in other cases, where disintegration does not take place, the magnifying glass reveals the tendency to break. There is a considerable difficulty, arising from the nature of their construction, in lifting the sections in and out of the pots. It is also impossible to see between the plates, since the forks obstruct the light; and re-pasting, if required at any time, would be a troublesome operation. The insulating saddles are a source of annoyance, for being slight and brittle, they are apt to break.

The author's method of building up the plates has been somewhat improved in detail, and cells in his

possession show no deterioration on account of the simplicity of the system.

The balance of good and evil, in regard to plates being placed farther apart, will be spoken of in another volume.

Those who have used primary batteries know only too well how zinc plates eat away near the surface of the liquid. This is due to the increased electric action, *i.e.*, current density, at the upper part of the plates. The reason may be thus explained. It may be assumed that the current starts from every part of the plate to the outside circuit, and consequently the current starting at the upper parts of the plate will travel through a less resistance than that starting at the lower parts; in other words, the chemical action will be more vigorous near the surface of the liquid. A similar action takes place in secondary batteries, which in practice shows itself by the plates becoming more quickly charged and discharged near the upper portions than the lower. As a consequence, for rapid discharges some method must be devised of making the resistance between the upper and lower portions of the plates as small as possible. This can be accomplished in a variety of ways, *viz.*, by having a large quantity of conducting metal along the perpendicular edges of the plate, or by making the grid itself massive, or by having additional conductors to the bottom of the plate, so that the charging and discharging currents may enter and leave the plate simultaneously near the top and at the bottom. Such a requirement was recognised by the Electrical Power Storage Company many years ago, when they produced what was known under the name of the "hanging type" of plate. After a short time it was abandoned;

but history always repeats itself, and the type has (with slight modifications), at the beginning of 1891, been reproduced as a new one, under the name of the **K** type for heavy discharges, the cause for their reappearance being that there is a considerable demand at the present moment for batteries capable

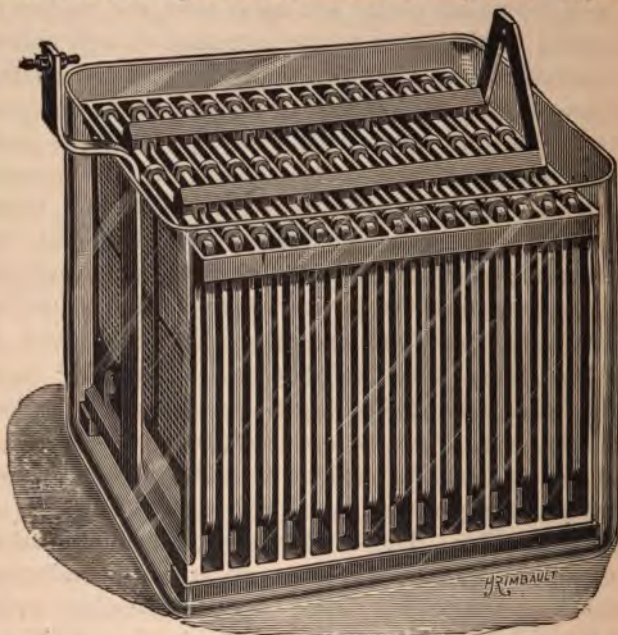


Fig. 6.—**K** or High Discharge Type (Electrical Power Storage Co.).

of giving heavy currents. The reason why these cells were originally termed the hanging type was that plates of one designation were suspended between those of the other name, one set, of course, being insulated from the other.

The **K** type of cell is shown in fig. 6.

The construction is sufficiently clear from the diagram to require no further explanation.

The plates in this type are of a special construction, which will be described later.

The defunct Electrical Power Storage Company has again come to life. The Electric Construction Corporation has now given up the manufacture of secondary batteries, having granted a licence to the E. P. S. Co. In the succeeding pages the only distinction that must be drawn, when speaking of the E. C. C. and the E. P. S. cells or plates, is that of dates; for the wares may be the same in both cases. These designations simply refer to the period when the goods were made. As the Electrical Power Storage Company is now the only one which manufactures pasted plates in this country, all plates of this type are spoken of as E. P. S.

The author addressed a letter to Messrs. Elwell-Parker early in 1887, suggesting many new methods of building up the sections, some of which were included in a patent taken out at the time. He specially recommended that the plates should be placed further apart and the holes formed on grids of such a size that any plugs of paste falling out should drop clear to the bottom. He also suggested the prolongation of one set of plates at their lower end, in order to avoid the possibility of any deposits creating short circuits, partial or complete. This improvement also permits of the old-fashioned wooden frames being dispensed with. He likewise advised making the holes smaller at the surface of the plate than within. The method of building up enables the forks to be dispensed with, so that there is between plate and plate an uninterrupted sight-way

available between for their examination, and also an increased storage power amounting to about 10 per cent.

The author's type of coil is shown in general view in fig. 7.

Unfortunately, all these points were not immediately put into practice ; they were later, and with the anticipated advantages. The plates have small projecting lugs cast upon them at their edges. (See fig. 5.) These lugs fit into holes in slips of ebonite, which fulfil

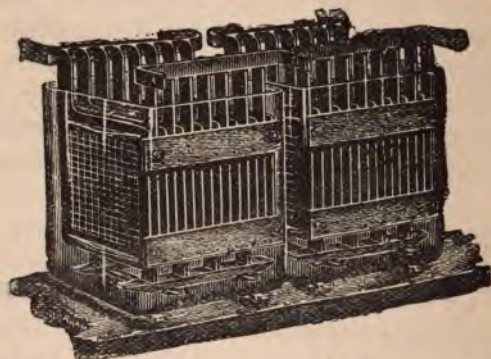


Fig. 7.—E. P. S. Cells. General View. The Author's Method.

the treble function of forming the supports for the plates and the frame for the sections, as well as doing duty for distance pieces for the plates. The projecting pieces of the positive and negative plates are cast at different levels.

At each end of the section a skeleton lead-plate is placed, having short horizontal projections or horns with slots in them. These horns pass through the ebonite strips, and wedges having been pushed through the slots the section is rendered rigid. Fig. 7 shows the author's

sections as built before the separate skeleton lead plates were employed. The only difference in appearance between the old and the present method is that, whereas the horns of the end negatives are seen to come through the ebonite slips with nuts upon them, the wedges are now visible which hold the end plates.

In the earlier form of the above-named type of section these lugs were cast on the end negatives; but practice proved this not to be advisable, because occasionally the pieces snapped off and the rigidity of the section was lost. Also, in taking the section to pieces, it was no infrequent circumstance for one or more of the horns to break off, and when this happened it became necessary to remove the faulty negative and to "burn" on a perfect one. By using separate plates, as mentioned, should any accident occur in the way indicated, the plates need not be interfered with: it will only be needful to take a fresh skeleton plate. From these remarks it might be supposed that some trouble would be experienced in this method of building up the sections, but on two occasions only, in the author's experience, have the sections come apart by reason of these old pattern screwed lugs breaking—an accident which occurred during their transit from Wolverhampton to Tunbridge Wells. Ebonite slips, hair-pin shaped, generally called forks, are entirely dispensed with between the plates, thus giving a clear way for observation between the plates; which, in practice, implies that the battery would have a longer life. In the E. P. S. 1888 and the K types the forks must under no conditions be removed, or the section will collapse, positive and negative plates coming together.

The grids, made of alloy of lead and ten per cent. of antimony, are passed through a special machine before pasting. The machine is so constructed that it gives the plate slight blows with very great rapidity; the holes become burred at their edges, and, in consequence, the cavities are larger within the grid than at its surface. This improvement is due to Messrs. Drake & Gorham, and is patented by them. An equivalent process had been suggested by the author some years previously, and his method is the best, if it can be carried out successfully in practice. It is well known that if a plate of metal containing holes truly drilled or punched is rolled under pressure so as to reduce its thickness, these holes become barrel-shaped, the smallest ends being at the surface of the plate. Consequently, the rolling process and the burring process apparently attain the same result. But there is one important distinction: with surface contraction, obtained by rolling, the plug of paste is wedge-shaped; whereas with the burring such is not the case. And experience has shown that this burring process will not secure the paste from falling out, if the cells are badly used; but from experiments made by the author it appears that the plugs keep in place, under all conditions, with the rolling process. However, plates which have been burred possess at least one advantage, viz., that of securing the paste in place during transport and rough usage.

The negative plates are prolonged at their lower edges at each end, so as to keep the plates well away from the bottom of the pot, standing, as it were, upon two short legs. The pastes employed are very hard. The holes in the positive and negative plates are similar in size, and the distance between the plates is so regu-

lated that, should a square of paste drop out, it would fall to the bottom.

There are lugs, as usual, for connecting the plates; but, instead of soldering or burning on a strip of lead, the strip is cast on to the ends of the lugs. This method, which is more convenient and looks neater, is now generally adopted.

The electrolyte consists of dilute sulphuric acid. The sections rest on wooden frames or blocks, in order to avoid the risk of breaking the pots, although their presence is not essential.

The most approved and modern cell, with pasted plates, of the present day is the E. P. S. K type, which has already been referred to. Its mechanical construction is practically identical with that which was introduced many years ago by this company, when Mr. Drake was one of the chief officers, and the sections were termed in those times the hanging type. Mr. F. King has present charge of the works. The positive plate is virtually similar to one which has been long in use on the Continent, and there known as the Tudor plate. The grid is a solid lead plate, with narrow horizontal grooves close together; these are filled with the paste and slightly burred over. The negative plates are of the usual kind.

The main advantages to be derived from this type are the following:—(1) Larger charging and discharging currents can be employed; (2) less liability of the paste to fall out; (3) for their charging and discharging rates, lightness of weight; and (4) probable long life. On the other hand, for the actual space occupied their capacity is not so great as in the older type. Again, in consequence of there being so much lead in the grid—which is usually prepared in a spongy form—this plate

may be regarded as a combination of the plain and pasted types; and, consequently, a longer period must elapse before they attain their maximum capacity.

The only improvements which appear possible in the **K** type of section to render this an ideal section of the pasted type, in the present state of knowledge, are two:—(1) the forks should be replaced by celluloid combs, as in the Crompton-Howell cell; (2) and probably spongy lead plates could be employed with advantage for the negatives, thus doing away with the grid of squares which now have teeth filled with paste.

There is a modified **K** type, wherein perforated celluloid separators are used. These cells are intended to withstand the bad effects of vibration.

There are many foreign manufacturers of accumulators who employ pasted plates. Since these plates are in every instance modifications of those already described, only a superficial account of some of them will be necessary for the sake of indicating a few possible variations. In several forms the plates consist of pockets made of thin perforated lead, which are filled with the lead oxides, the end in view being that the paste shall not fall out when employed for tramcar work. One of the best of these forms is the Johnson plate, made in America; and in this one the thin lead of the pocket is corrugated, as well as being perforated. In others the grid is corrugated and pierced in a variety of ways, the paste filling the interstices. A small Johnson cell, tested by the writer, has withstood hard usage without injury.

There also exist many plates in which the grid is reduced to a mere frame or is even dispensed with altogether. Such, for instance, is Mr. Fitzgerald's solid

peroxide plate, to which he gives the name of the lithanode plate.

The plates made for Messrs. Rothschild, of Paris, have the paste cast within the grid, the latter being porous at the surface.

The Tudor plates, so largely used on the Continent, have grids with narrow horizontal grooves close together, which are burred over and filled with the paste.

The grid is first prepared in the same manner as

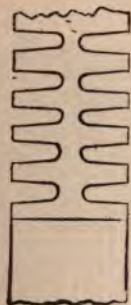


Fig. 8.—Tudor Plate.
Section: empty.



Fig. 9.—Tudor Plate
Section: pasted.

the plain lead or Planté type. Fig. 8 shows a section of the empty grid, and fig. 9 the grid pasted and burred over.

The Johnson & Phillips, the Epstein (supplied by Messrs. Woodhouse & Rawson), and the Crompton-Howell plates are of the spongy-lead type, and differ mainly in their mode of manufacture and method of building up the sections.

The Johnson & Phillips plates are manufactured for Messrs. Drake & Gorham, who hold the patents. These plates are built up of lead ribbon placed horizontally in a frame of an alloy of lead. (Plate 10 shows two of these cells.) The makers

state that the advantage of these plates over the pasted kind is that, size for size, they may be charged and discharged at much higher rates. Messrs. Johnson & Phillips term their plates the D. P. type. They are of moderately recent manufacture, viz., about three years. They are of the usual pattern, and the sets of positives and negatives which are to be formed into one section are cast on to leaden strips put together in the ordinary way, ebonite forks being

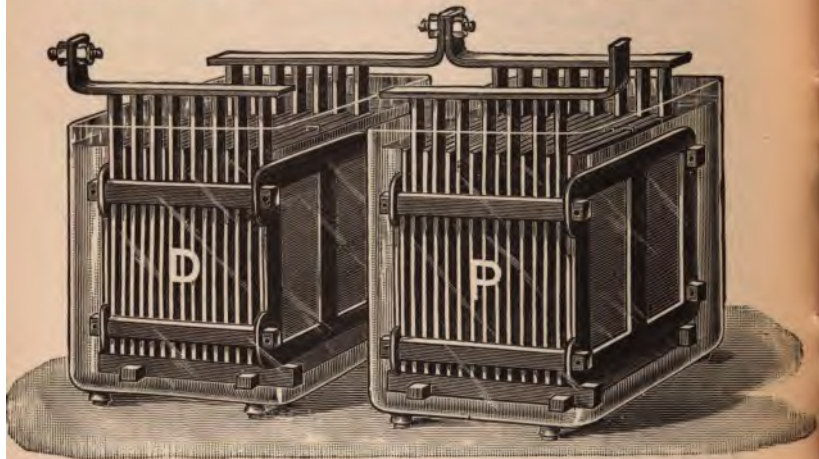


Fig. 10.—Johnson and Phillips' Cells.

used as separators (*i.e.*, to insulate one plate from another). The section is kept rigid by paraffined wooden strips, which are held together by leaden skeleton end-plates and by means of wedges. The lower ends of all the plates have, until recently, reached to the same level, in consequence of which there is a possibility of short circuit in the event of deposit. The writer has pointed this out, and believes that, in order

to remove that disadvantage, the one set of plates will in future be made longer than the other.

The firm informs the author that they have adopted the suggestions which were put forward, and advantage has been found to result. Some more recent cells are carried upon thick bottom legs, these latter resting on sharp-edged bottom blocks; which arrangement appears to remove the difficulties referred to,

Two cells that the author has under experiment have worked very well; but as he observed that both sets of plates reaching to the bottom of the cell was a drawback, and that no satisfactory test could be made in consequence, the edges of the plates, instead of being allowed to rest upon the two sides of the bottom wooden frame, were made to stand upon two glass rods; which implies that at any place where a plate stands it touches a line instead of a surface. This method is mentioned to indicate how users may overcome the difficulty, should it occur at any time in a similar build of section otherwise found to be good.

The Epstein plates are very thick, and the number of plates in a section are few when compared with sections of other makers and intended to do the same work. It must, therefore, be inferred that some method is employed to increase the surface of the plates, and

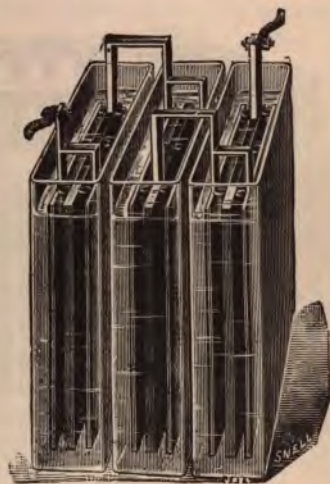


Fig. 11.—Epstein Cells.

such is the case. On looking at a plate, parallel lines will be noticed drawn very closely together over the whole surface. Each of these lines, when carefully examined, will be observed to penetrate, like a saw-cut, for a considerable depth into the plate. Technically, every plate surface may be described as rectangularly corrugated; and upon looking at a plate edgewise, this configuration becomes very clear. The

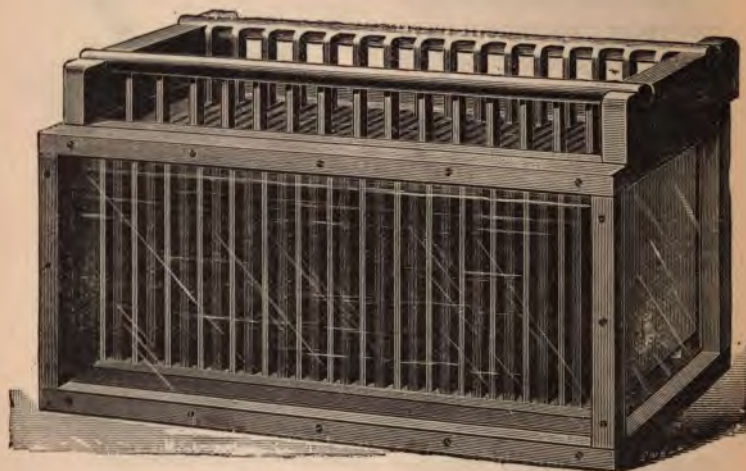


Fig. 12.—Epstein Cell.

consequence is that each plate, apart from the quality of porosity, has an exposed surface far greater than would have been the case had these corrugations not existed. Fig. 11 illustrates three of these cells joined together, each section consisting of one positive and two negatives.

Fig. 12 shows a larger cell.

These sections are built much in the same way as

usual. The separators are glass tubes, placed vertically. Although this cell is of recent introduction, the writer can speak well of it, but he finds that the capacity is low for the size of section. There is nothing absolutely new about the plate. It is only a case of "ringing the changes." In order to give a notion of the work to be expected from these plates, it may be mentioned that, according to the maker's statement, in one size the ampère-hours capacity will vary from 90 to 130, according to the rate of discharge lying between the limits of 45 and 13 ampères. The total weight of this cell, including the acid, is approximately 40 lbs.; and the size of each plate is much the same as that of the E. C. C. plate. In passing, it may be remarked that the capacity, varying with the rate of discharge, is common to every type of plate. The author has not been able to obtain such high results, as mentioned, in practice.

The Crompton-Howell battery, as already described, is also of the spongy-lead type, and the form given to the plates is the customary one, but the size is larger than any other of the present makes of pasted-plate type. The sections are not built up rigidly at all. The separators consist of small celluloid pieces, in appearance like a comb, each tooth having a width equal to the distance between plate and plate, and the space between each tooth being equal to the thickness of the plate. The teeth are about three-fourths of an inch long. The separators, which are used for the lower portions of the plates, are similar in form, but in two rows; and the back part of the combs are extended and carry feet, thus enabling them to stand alone. In this way the plates are kept from the bottom of the pot, risk of short circuit from any deposit being averted. Fig. 13 shows the separators with one

plate in position. The plates are placed together as follows:—Two or more lower separators are put at the bottom of the pot (for stationary work a glass pot is generally used) upon a frame, or on slips of wood, so as not to break the glass by unequal pressure.

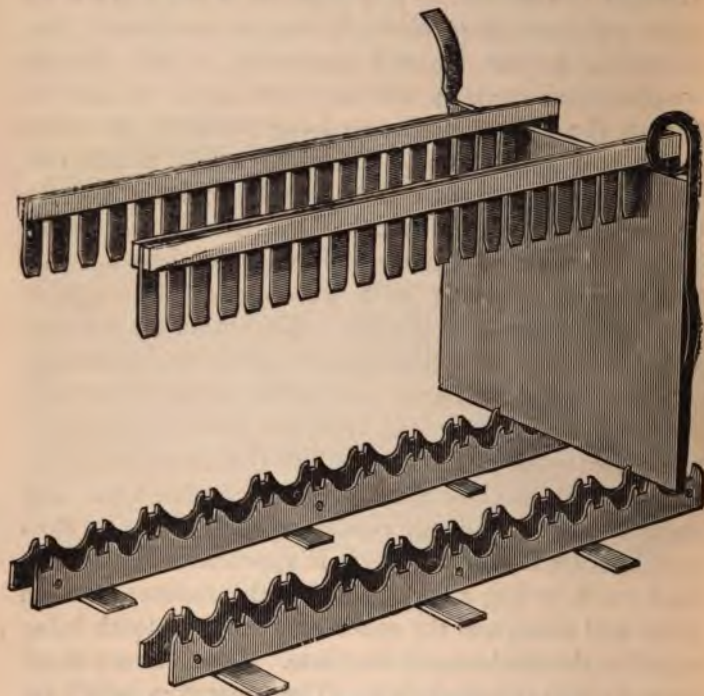


Fig. 13.—Celluloid Comb Separators for Crompton-Howell Plate.

The plates are then placed into the teeth of the lower combs, positive and negative alternately, as usual, so that the lugs of the positives range on one side of the glass cell and the negatives on the other. The upper combs are now pushed in, the section is then fairly rigid, and

the tail-pieces are burned or soldered on to strips of lead, which are so large in section that the designation of "block" would be more applicable than "strip." Fig. 14 shows two of these cells joined up together. The ring seen at the end of each plate, opposite to where the lug

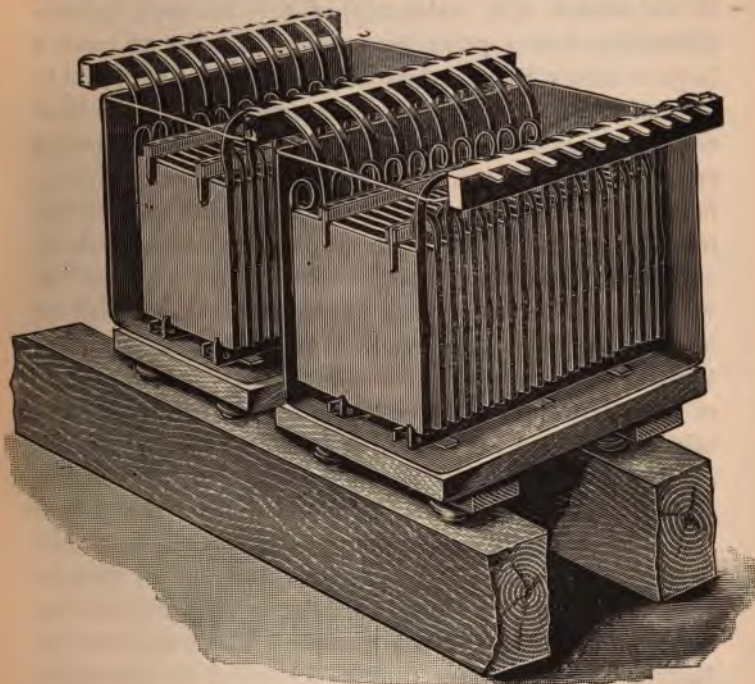


Fig. 14.—Two 21-plate Crompton-Howell Cells.

is, has for its object simply the convenience of lifting up the plate.

In some instances the plates are soldered to their strips before being placed in the pots with the insulators, but which method is to be preferred depends a

great deal upon the workman. It may be said with truth that these sections are the most troublesome to build up of all at present in use, since much care is required, because the plates are heavy and their lugs frail. The object of such heavy connecting strips is to reduce the resistance of the battery connections to as low a point as possible, in order to enable large currents to be taken without waste. When this form of battery is intended for heavy currents, the lead connecting-strip of one set of plates in one cell is made common to those of a set of plates in the next cell, *i.e.*, lugs of the positive plates in the one and those of the negative plates in the next are soldered to one strip, as shown in fig. 14. This is not the ordinary practice with most batteries. In all other cases it is desirable to keep to the customary practice of connecting the cells together, and for two reasons : in order (1) that the edges of the plates may be seen, so that paste or scale sticking between the plates, or buckling, can readily be observed and immediately remedied ; and (2) that the sections may be more easily removed from the pot at any time. By connecting section to section, as shown in fig. 14, the resistance of the battery is reduced to a minimum. At any moment a single plate can be renewed without much trouble. The owner of the battery must, therefore, decide, according to the nature of the surrounding circumstances, which method of connecting up is the best. A large cell, such as would be used for central installation work, is shown in fig. 15.

In this case the connecting strips are so heavy that they are supported by porcelain insulators carried by iron rods. The demand for these batteries in private instal-

lations has so much increased that a new kind of section is now made, which overcomes many of the difficulties already mentioned in putting them together. The plates are made up into sections supported by celluloid separators in the form of a cage, enabling the section to be easily lifted in and out of its cell. It is desirable that the connecting strips be supported upon pieces of paraffin waxed wood, resting upon the edges of the pots.

The form of separators employed has a decided advantage over the forks used by other makers, since it allows of the spaces between the plates being seen right through without obstruction. Great care must be taken when putting up these sections to see that they are placed square. The author has had many of these cells under observation for a considerable time, and they have acquitted themselves creditably in every way.

Messrs. Crompton have been kind enough to furnish a description of the manufacture of the Crompton-Howell plate, and, as it is likely to prove of interest to the reader, the information is now given. Lead is melted and permitted to cool to a certain extent. During this process crystals, of the metal, form at the bottom of the pot, and they are removed by means of perforated ladles. Iron moulds are filled with these crystals, which are then surrounded by a certain amount of molten lead, and the blocks are allowed to solidify. When turned out of the moulds these blocks are approximately 2 ft. long by 10 in. square. They are cut up into plates of any desired thickness, generally $8\frac{1}{2}$ in. square by $\frac{1}{4}$ in. thick. The plates, having had their lugs attached to them, are made up into sections, placed in cells with the electrolyte, and connected up, to be formed by passing a current of electricity through

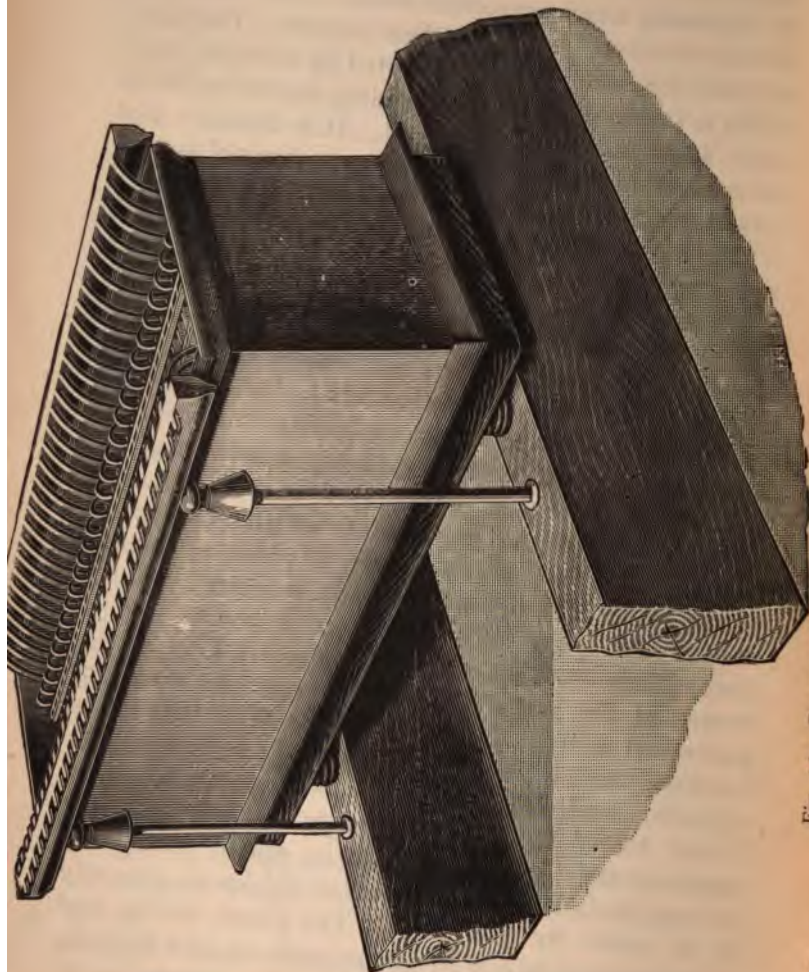


Fig. 15.—Crompton-Hewell & Co.

them. The plates are so porous that every crystal can be reached by the electrolyte. The active material is formed right through the plates as a firmly adherent coating to the lead crystals, and does not fall away. Being created electrically, the coating is in intimate



Fig. 16.—Complete Frankland-Lithanode Cell.

connection with the lead basis of the plate. Also, for this reason, the plates are less apt to sulphate badly than in the case of the pasted type of plate, since the material comes well into action during the working of the accumulator.

When formed, the capacity of each plate of the size

mentioned is, approximately, 40 ampère hours ; and they may, without injury, be discharged at a rate not exceeding 10 ampères per plate.

Professor Ayrton, in his paper read before the Institution of Electrical Engineers, at Edinburgh, in 1890, stated that the connections of the E. P. S. battery, upon

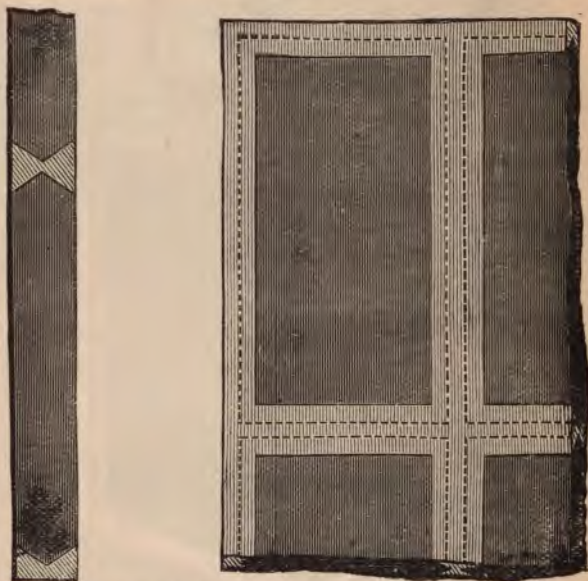


Fig. 17.—Section and Elevation of Frankland-Lithanode Element.

which his experiments were conducted, had a resistance equal to 14 per cent. of the total resistance. Almost the whole of this wasteful resistance is eliminated in the Crompton-Howell method of connecting the battery er. (See fig. 14.) Theoretically, therefore, the y of the battery ought to be at least 10 per cent. an the E. P. S. accumulator. But this statement

must be taken under reserve, because in reckoning efficiencies so many other questions enter. For heavy discharges, however, the advantage is enormous. Messrs. Crompton state that, where accumulators have been in use four years, the renewal of the positive plates has not

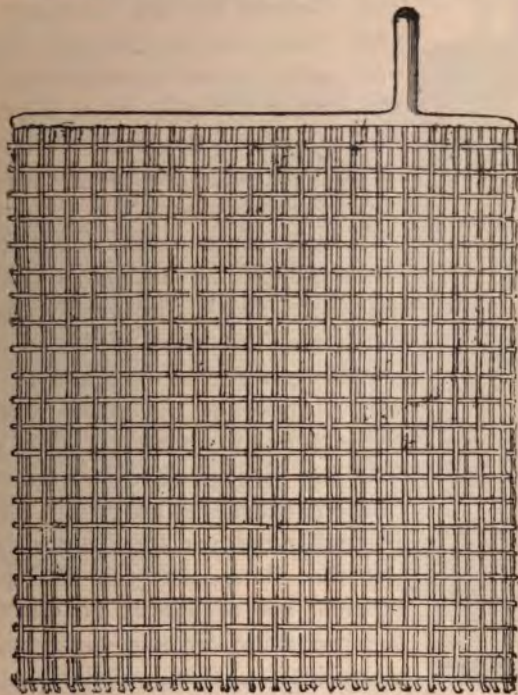


Fig. 18.—Copper Mesh Spongy-Lead Element.

exceeded 6 or 7 per cent. of the total number of positives a year, and that the renewal of the negative plates was so small that no estimate can be given. The writer's experience is more favourable than that given by the makers.

The manufacture of lithanode has again come to the front. Mr. Fitzgerald and Dr. Frankland have combined their energies in the production of, what are now termed, the Frankland-Lithanode storage cells. The



Fig. 19
Glass Test Cell.

makers of these cells are the Lithanode and General Electric Company. The chief distinction between the lithanode and pasted plates is, practically, that in the former the grid takes a very subordinate place, the bulk of the plate being the paste; whereas in the pasted types the grid forms the greater part. Although his experience is limited to small plates, the author can, notwithstanding, speak favourably of this material. The whole of the rules which should be observed in regard to pasted plates apply in the same manner to these lithanode plates. The risk in buckling is somewhat less on account of the lightness of the grid. The same paste is employed for the positive and negative plates, and the final qualities of each set of plates is effected in the process of forming as usual. The electrolyte is dilute sulphuric acid, *s.g.*

1.200.

Fig. 16 shows a complete cell.

Fig. 17 exhibits a portion of a plate and a section through part of a plate. The darker shading indicates the lithanode, and the finer shading the grid. These illustrations need no further description. When great lightness is required, the negative plate is made in a

novel fashion, and consists of a double network of copper gauze (shown in fig. 18), which is then coated with lead and afterwards filled with lithanode which has been partially formed.

When this plate is dry and hard, it is reduced to a spongy condition by electrolysis. This copper grid



Fig. 2c.
Lithanode Miner's Lamp.

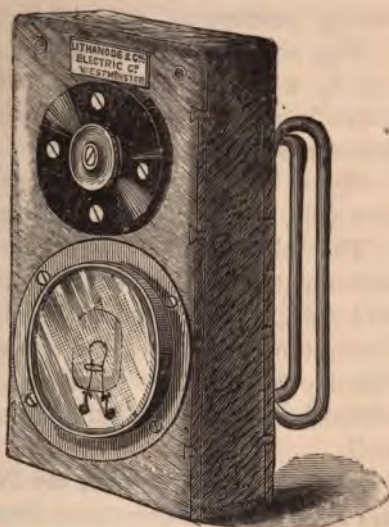


Fig. 21.
Two-Cell "Pocket" Lamp.

is an excellent conductor, and being coated with lead, the copper is protected from the action of the acid. Sections made up after this method, *i.e.*, the lithanode, positive and the copper-grid negatives are very light compared with the older forms mostly in use; and when it is considered that, notwithstanding this reduced weight, there is a greater capacity, having

regard to the size of the section, than in other forms, for the reason that there is a large proportion of paste in their constitution, the advantage gained is manifest.

These cells are made in small sizes for miners' lamps, portable lamps, and testing purposes, as well as in sizes capable of being charged, or discharged, at a rate as high as 70 ampères.

Fig. 19 shows a cell employed for laboratory and testing purposes.

Fig. 20 illustrates a miner's lamp, weighing $4\frac{1}{2}$ lb.; which, when fully charged, will produce a light of 1-candle power for a period of twelve hours; a 2-cell battery being employed.

Fig. 21 shows a very small portable lamp, containing two cells, and giving a light for four hours.

The oldest public lighting companies which use accumulators are the Kensington Court Electric Supply and the Chelsea Electric Supply, the former using the Crompton-Howell and the latter the E. P. S. cells; but the day is too early to form a decided opinion as to ultimate success or failure, though, so far, all has gone well.

At the present moment the following central stations are also using the Crompton-Howell battery, of the type shown in Fig. 10:—Westminster Electric Supply Company, Notting Hill Electric Lighting Company, Bradford Corporation, Liverpool Electric Supply Company, Birmingham Electric Supply Company, and at Gothenburg; besides being in extensive use in Australia, America, and other parts of the world.

Mr. Barber-Starkey has experimented by filling the spaces between the plates with plaster of Paris and sawdust intimately mixed, and he states that the result was

successful. (See *Electrical Review*, July 18, 1889.) For traction work this treatment may be good, but the internal resistance must be greatly increased in consequence. Felt and other materials, including a "jelly" electrolyte, have been used to act as separators.

Messrs. Hulsen, of Newcastle-on-Tyne, make a solid sulphuric acid, in combination with soda (Brindley's Patent); and this chemical appears to answer well for the electrolyte. The crystals must be gently dissolved in water and brought to the proper specific gravity before use. This substance is deliquescent.

Wherever wood is employed as a constructive part of a section, the author prefers to substitute ebonite; and at Broomhill this material has been introduced in all such cases, the extra expense being approximately ten shillings per cell; an outlay which has only to be incurred once, because the ebonite can be used over and over again. The objection against the use of wood in the electrolyte is more sentimental than real, for if this material has been thoroughly saturated with a hydrocarbon, the electrolyte does not attack it, and consequently it does not become a conductor. Pieces of wood so treated are in the author's possession; they have been in the acid solution many years, and show no trace of deterioration or tendency to conduct. He, therefore, is satisfied that there are no grounds for the objections taken, provided that the wood has been thoroughly prepared. Yet, for neatness of appearance, ebonite is the best, and never deteriorates. Celluloid is a good substitute for ebonite or wood.

The following remarks apply to all types of pasted plates. Dilute sulphuric acid is poured into each cell in sufficient quantity to cover the plates. The cells are now

connected in series, and a current is passed through them for a long period, causing the paste on the positives to become converted into lead dioxide; but the conversion is not complete, as will be explained later, and the paste on the negatives becomes partially reduced to finely divided lead. This process having been gone through, the sections are said to be formed, *i.e.*, ready for use. More will hereafter be said on this point.

With regard to charging and discharging, it will be shown in a future chapter that the whole process is a sulphating one. When the paste upon the plates is in such a condition that only with difficulty can it be reduced to peroxide of lead, it is usual to describe the plates as being badly sulphated. Therefore, when the plates are said to be "sulphated," this is an abbreviated expression for deleterious sulphating. The term "fully charged" must be taken to imply that it is charged sufficiently for practical purposes. The chemical process is the same for lead plates of any type.

The positives may be distinguished from the negatives by their colour, which is variously termed plum, chocolate, red, and dark red. The negatives have a greyish tint on the surface, and a pale slate colour at their edges.

Whatever may be the type of cells used, care is always necessary, though, at the same time, an intelligent man, guided by a competent teacher, will soon learn for himself what should be done on all occasions likely to arise; and, with proper attention, the troubles which so many persons encounter would never occur.

Every cell with lead plates, no matter of what kind, unless exhausted, gives a pressure of 2 volts as near as possible. Thus one cell is valueless for lighting

purposes, because pressures from 50 to 100 volts are required for practical use. At the present day the pressure of 100 volts is universal for incandescent lighting, any other pressure being quite the exception. Consequently, an accumulator consists, in a majority of cases, of 50 cells, or of two or three more than this number, so as to allow a few extra for reserve.

The cells are connected with one another by joining the leaden strip, uniting the positive plates in one cell with the strip, connecting the negatives in the next one, and so on (figs. 4 and 7); or by the other method explained when describing the Howell-Crompton cell. They are then said to be connected in series. The strips may be joined by solder, by bolts and nuts, or by clamps.

Cells can also be connected in parallel, whereby two or more may be made to act as a larger one of twice or more times the capacity of the single one (*i.e.*, if all are of equal size); but the E.M.F. will be that of one cell only. Cells of unequal size may be coupled in like manner. Again, cells may be connected first in parallel, then in series. It is also clear that more complex arrangements are possible, such as cells in series placed in parallel and then again placed in series. All combinations have their uses, under special conditions; but, in practice, it is always better to choose the simplest combinations.

To give an instance: suppose in an installation requiring 100 volts, double the capacity is required with the same pressure, and larger cells are not to be employed; then, if 54 cells were first installed, these must be increased to 108, which may be coupled in one of two ways for giving the required result. One way is by coupling

these cells two and two together, thus : the positives and negatives of two cells are joined together by their connecting strips, positive to positive and negative to negative ; these two cells are then treated as one cell, the positive at one end being joined to the negative of the next couple, and so on. Another way is to arrange the 108 cells as two complete batteries of 54 in series, then to join the positive ends of these two batteries together, and also the negative ends, this method being termed "two batteries placed in parallel." When cells are placed two and two, if the pressure of any two so coupled differs ever so little, from any cause whatever (and, in practice, the pressure of no two cells is the same), it is evident that the one which has the greater pressure will discharge into the other which has the less, the practical result being that a battery, made up on this system, will get out of order in a very short time. This method may, therefore, be discarded as an impracticable one (a lesson taught on a large scale at Lloyd's installation) ; whereas, if two batteries are connected in parallel, the sum of the pressures of the cells in each battery will be found to be virtually equal. If any variation exists, the difference in pressure (assuming that all the cells are in good order) will be so small that any current flowing from one battery to the other will be almost inappreciable ; consequently, the battery runs no risk of being injured.

Another advantage exists in the use of the parallel battery method. If a glass pot in a single battery were to break and the electrolyte to escape, it is clear that the circuit would be cut and all lamps supplied by the battery extinguished, if the dynamo is not running. Should, however, the dynamo be running, it is almost

certain that every lamp in use at the time would be destroyed. But the probability of a cell breaking at the same time, in each of the two batteries placed in parallel, is very remote ; so that an accident arising from one glass cell breaking would produce no inconvenience. Besides, an opportunity is given at any moment to change, repair, or clean, one battery, leaving the second to supply the light. The breaking of a glass pot happened on one occasion in the author's installation, when the value of two batteries in parallel was proved. Any number of batteries may be placed in parallel according to the requirements of the case.

There is another way of obtaining some of the advantages derived from the use of batteries in parallel : the method is that of placing two or more sections in one pot, and connecting them together in parallel. Thus a section may be removed for any purpose without breaking the circuit. This system is more suitable for public than for private installations, because each cell becomes very heavy and large. The parallel battery system on balance is the best, when all points are considered.

Other advantages arising from the use of batteries in parallel will be pointed out in another volume of this work.

CHAPTER II.

SETTING UP THE CELLS AND THE ACCUMULATOR-
HOUSE.

ON their arrival, the pots, whether of glass or other material, should immediately be unpacked and got ready for the sections; for, unless the air is dry, the plates will be injured by exposure. Since glass pots are employed almost universally in stationary work and require the most care, it will be assumed in the following chapters that such cells are used. At the same time it must be borne in mind that many of the recommendations in respect to glass cells may be applied with advantage to those made of other material.

Strong shelves, for the reception of the battery, must be prepared, and small boards on which to place each cell. Every board stands upon porcelain, or glass, insulators; which in certain patterns may be filled with oil, to insure better insulation (see figs. 22 and 23). The glass pots, which are best for stationary work, should be placed along the shelves, and upon the boards which rest on the insulators, leaving about an inch between cell and cell; but they must on no account touch. The purpose of the boards is to prevent the insulators from cracking the glass cells by an unequal distribution of the weight. The shelves and cell boards should

be varnished, for the sake of insulation as well as cleanliness.

Some makers recommend, instead of these boards, wooden trays, filled with sawdust; but they are best avoided, as the sawdust becomes saturated with the electrolyte, and gives rise to considerable annoyance without one single advantage. Outside of each cell, and close to the mouth, melted paraffin wax should be applied by means of a brush, so as to form a band about an inch broad. The best way to heat the wax, without burning it, is to melt it in an ordinary glue-pot provided with an exterior water-vessel. The band of wax prevents the liquid from creeping over the top, render-

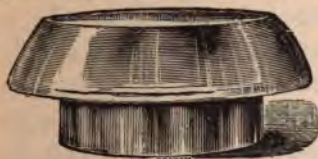


Fig. 22.

Oil Insulator. General View.

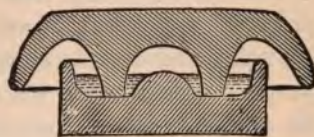


Fig. 23.

Oil Insulator. Section.

ing the outside wet, and thus impairing the insulation. It is of the highest importance that every cell should be perfectly insulated, in order to avoid waste by leakage. Bad insulation in the accumulator-house may even prove a danger in the dwelling-house.

Each section, or the individual plates intended for one section, is sent out from the factory in a separate box or crate. They must not be handled roughly. When the plates are sent out already built into sections, these must be unpacked without disturbing a single plate, and every particle of packing, if of straw, must be removed. Any chips, or any bits of paste, which may be found sticking between the plates, should be carefully taken

away. A bellows may be used to blow the dust from between the spaces. In fact, the spaces between the plates must be absolutely clear, for future success in the working of the accumulator depends in a great measure on the way in which the sections have been unpacked and freed from rubbish. It is true that straw and wood are good non-conductors, but the action of sulphuric acid upon these substances carbonizes them. In that state they have considerable conducting properties, and their presence between the plates would produce leakage. At this stage it is supposed that the pots have been cleaned, the edges waxed, the cells placed in position upon the shelves, and the plates all unpacked.

The sections are now put into the cells. In a properly appointed accumulator-house this is simple enough; and the arrangements best adapted for the purpose will shortly be described. But the plan to be adopted, where luxuries do not exist, will first be considered. Remove the first glass cell from the shelf, and place it upon a piece of board laid on the ground. This board should be somewhat narrower than the cell, in order to facilitate the lifting of the latter when the plates are in. The support for the section, consisting in most instances of a skeleton wooden frame paraffin-waxed, is first put in the pot. When such a frame is employed, it must be carefully placed in the proper way, so that the thicker sides of the frame bear the weight of the plates. Observe also that this frame is placed right way up, so that it may take an even bearing upon the bottom of the cell; for, if it does not take an even bearing, the glass will probably be broken by the weight of the section. In order to guard against such an accident in those cases where

the wooden frame does not fit the bottom of the pot, wedges of paraffin-waxed wood must be placed beneath the frame, so that the weight may be equally distributed.

Now lift a section clear of the cell; lower it gently till it reaches the bottom and rests fairly upon the frame, taking care to observe that the plates have not shifted, and are quite straight and central in the cell. The section must not touch the sides of the pot, but should have a small clear space all round. Frequently the mouth of the cell is square, but if not, allow the greater space to exist between the edges of the plates and the sides of the vessel, unless the dimensions of the sections are such as not to admit of their being placed in that manner. This gives room for the acidometer, which is shown in fig. 27. Hooks will be found most convenient for lifting the sections from the packing-cases, and then putting them in the cells. In most cases two men are required for this purpose, the sections being very heavy. The hooks consist of a piece of iron wire, about No. 1 S.W.G., formed in the shape of the letter **U**; the free extremities are again bent into hooks, each half-circle being about two inches in diameter. The plane in which the hooks are turned is such that they are not seen when the whole is viewed as a letter **U**. In order to avoid cutting the hands while lifting, a piece of half-inch iron gas-tube is placed on the bend of the **U**, which is made square to enable this to be done, the tube having been slipped on before the wire was bent up.

When employed to lift the plates, one pair of hooks is applied to the positive lead strip, and one pair to the negative. In this way two persons can lift small or large sections with ease, and lower them gently into

the cells without risk of breakage. Sections are now made in so many different ways that no general mode of lifting into the pots can be indicated, and in most cases their construction shows some method of procedure which is evidently the best; but these lifting hooks would, in the majority of instances, be found useful.

Each cell, when completed, is put back into its place upon the shelf. To effect this in the best way, lift the cell now upon the floor on to its cell-board, and then lift the whole together into position upon the insulators. For high shelves, a staging (*i.e.*, tressels, with planks laid across them) is necessary, on account of the great weight to be raised.

When all the cells are in position, they are ready for connecting. The preceding chapter describes the methods of doing this. Solder, or bolts and nuts, or clamps, are used according to circumstances. Solder is often employed in conjunction with bolts and nuts, or clamps; but this is not essential if there is a good surface of the lead strip of one cell in contact with that of the next, and provided these surfaces have been well cleaned. The ends of the lead strips are turned up, so that those of two adjoining cells with the junction appear thus:—

In some constructions the strips have to be bent horizontally, instead of vertically.

If the junctions are not in thorough contact, they will become hot when a current is flowing. It is desirable to make the connections include as little lead strip in the circuit as possible, thereby diminishing useless resistance and consequently waste. The insulators may be steeped in paraffin wax, which has the advantage

of increasing their insulating properties, besides permitting the boards, on which the cells stand, to be shifted with great ease; and in practice this is found convenient for placing them straight. The room should be cool and shady, for sunlight falling upon the cells is a constant source of breakage, which has often been attributed to some chemical action; but the true explanation is probably to be found in the unequal expansion of different portions of the glass.

Evaporation also is thus kept to a minimum. A water tap and sink should be in every accumulator house. When possible, it is a good plan to have a space behind the shelves wide enough for a man to pass. The edges of the plates can then be viewed from each side. The distance between shelf and shelf should be such that the cells may be easily looked into from above. If the battery be erected as mentioned, the edges of the plates will always face the person inspecting them. Brass or gun-metal clamps may be kept clean by brushing them over with paraffin wax, melted in a metal or glue pot, after they have been screwed up. The waxed connectors also give indications of bad contact, by the heat, generated at such points, softening the paraffin and causing it to appear of a different colour. "Anti-sulphuric acid paint," which resists the action of acid, can at present be purchased. This, as the word implies, is a paint that is not attacked by the electrolyte. For many years the author has used such a paint for marking positive connections red, and negative black. It is made of shellac dissolved in methylated spirit or wood naphtha (it may be bought under the name of shellac varnish), coloured with vermilion or lamp-black; but there is

no reason why any other colouring matter should not be employed, when desirable. This special paint, ready for use, may be obtained from Messrs. Griffiths Bros. & Co., of Macks Road, Bermondsey, London, S.E. It is sold under the name of Anti-sulphuric Enamel, and is guaranteed acid and oil resisting in its properties. This enamel is usually sold red, black, and transparent. The last-named is very useful for brushing over the connectors. The two colours will be found convenient for painting the positive and negative strips red and black, in order to facilitate the distinction of the plates, apart from other uses.

The author employs this paint extensively for the connections, marking the section strips, and for coating all conductors in the accumulator-house. He cannot speak too highly of this material, and it has proved of the greatest service. This enamel also withstands heat, and it is employed at Broomhill to paint the exhaust portions of the gas engines, causing these parts to look as nice and bright as the rest of the engine; which under usual conditions is never the case.

Clamps not made of a similar metal to that of the strips—which is almost invariably the case—frequently give trouble in consequence of the galvanic action set up between the two different metals in the presence of moisture, resulting in the destruction either of the leaden strip or of the clamp. The author has devised a very simple means of overcoming this difficulty, viz., by placing a thin slip of zinc sheet between the lead strip and the clamp, so that there is no direct contact between the two except through the zinc; for in the case of all metals usually employed for the connecting strips, as well as the clamps, zinc is the one

which is acted upon under the circumstances mentioned. Consequently, the portions likely to be injured remain intact; only the zinc crumbles away, and this, when necessary, can be replaced without inconvenience and practically at no expense.

All the difficulties encountered in lifting heavy cells in confined spaces are surmounted by erecting an overhead traveller, with dynamic pulley-blocks, on which hangs a suitable cradle, having an adjustable counterpoise. By this plan a cell may be placed upon a shelf, or removed, in a minute, no matter how heavy it may be. Such a cradle is shown in the frontispiece. The movable counterpoise enables the platform of the cradle to remain level, whether a cell is on or off it; and the point of suspension need not be over the cell, which would render its service useless where shelves exist.

The spanners employed in an accumulator-house should have wooden handles, to prevent the risk of making a short circuit when they are employed to tighten up the connections.

The floor should be of vitrified blue, or yellow brick, diamond pattern and falling in all directions towards a drain. This admits of the floor being easily washed by flooding it with water, and the pattern allows it to be dry under foot at all times. Wooden floors rot very soon by acid spillings and by the spray. The room should have nothing in it which spoils by contact with sulphuric acid fumes, while good ventilation is essential for safety and for the health of the attendant. A battery in use, and even when resting, gives off hydrogen, and when this is diluted with air a highly explosive mixture results. Therefore, if proper ventilation does not exist, an explosion will probably occur, should a

flame of any kind be brought into the room or near it. In addition to this danger, it would be almost impossible to enter the apartment during charging hours on account of the pungency of the atmosphere. There have been several serious accidents from the neglect of such a necessary precaution.

Those who put up batteries suffer certain inconveniences, *e.g.*, sore hands and the destruction of clothing. There is, however, a cure. The boots should be painted with paraffin wax, mixed with an equal quantity of beeswax; this compound being pliable. An apron of sacking, backed with common flannel, should be worn. The clothing ought to be of woollen material, sewn with worsted, not cotton; because wool is little affected by the acid. (In fact, the acid is a good test as to whether woollen goods are adulterated with cotton.) The shirt should be dipped in a solution of strong washing soda, and then rough-dried. By paying attention to these matters the clothing is fairly well protected. A bottle of ammonia fortis ought to be kept in the accumulator-house, in case of an accidental splash of acid on clothes liable to injury. The wetted stopper of the bottle applied to the stain at once neutralises the acid, and prevents a hole from being burnt in the material.

While operations are being carried on, a pail of water, rendered strongly alkaline with washing soda, should be kept close by, in which occasionally to dip the hands in order to prevent the skin from smarting under the action of the acid.

The cells are now supposed to be in position and connected together. All that remains to be done is to fill the pots with liquid, attach the dynamo cables, and

start charging. It is usual to paint the positive strips of the sections red, and the negative strips black, or to leave them unpainted; so that it is easy to distinguish the positives at a glance. If no mistake has been made in connecting up, the end cells of the battery have each a free strip, quite disconnected; one end being a positive and the other a negative. The positive end of the accumulator is joined to the positive cable from the dynamo, and the negative to the negative. The dynamo must be of the direct-current type and shunt wound, or special compound wound; but the former is by far the best. It is of vital importance that the reverse connections should not be made. Nothing, therefore, must be taken for granted; the dynamo wires should be tested. To determine the nature of the leads proceed thus: take a vessel of any kind—a jam-pot answers the purpose—and two pieces of sheet lead about 1 in. wide and 6 in. long. Nail these lead strips to a piece of wood, 1 in. square in section and 4 in. long, so that the lead projects beyond the wood at one end. The nails on the opposite sides, which attach the slips of lead, must not touch one another in the wood; and the latter is better shellac-varnished. By means of common clamps, such as are used for laboratory primary cells, join the projecting ends of the lead plates one to each dynamo cable, putting an ordinary 16-c.p. lamp in the circuit, so as to prevent too much current flowing. The dynamo cables are too large for these connections. Therefore, it is more convenient to attach a piece of No. 16 or 18 S.W.G. wire to the end of each cable for connecting up with the testing cell. Place in the pot dilute sulphuric acid, of about one part acid to ten parts water. Clean the mounted pieces of lead by

scraping or rubbing with sand paper; place them in the liquid, and start the dynamo. In a few minutes examine the strips of lead; one will have become brown, and the other grey. Then trace which dynamo cable is joined to the lead that has become brown. This is the positive cable, and it should have its end painted with red shellac varnish for future distinction. The test concluded and the dynamo stopped, the cable marked red is joined to the positive end of the battery by means of a suitable clamp, or by solder; and the other cable is similarly fixed to the negative end.



Fig. 24.—Pocket Pole Tester.

A very pretty little pole tester, recently designed and made in Germany, is supplied in this country by Messrs. Woodhouse & Rawson. It may be put in the waistcoat pocket, and can be used without a lamp or other resistance in the circuit. (See fig. 24, which represents this apparatus, full size.) It will be observed that there are two small knobs in the liquid, both of which are bright before using. The one connected to the positive wire remains bright, whilst the other becomes purple. After a test, the normal conditions are restored, because the purple matter, which has been

set free, becomes re-dissolved; a process which can be accelerated by giving a shake to the instrument, so that the latter is always ready for use.

The solution appears to be an iodine compound in glycerine. The author has found this little tester invaluable for attaching a variety of apparatus to an electric circuit, where it is important that the current should enter in a particular direction; also for testing leakage, to which reference will be made later on. These pole testers have recently been somewhat altered



Fig. 25.—Pocket Pole Tester, with Level.

in form. The metal mountings are varied and a small tube is added, the latter being used for a spirit level. (See fig. 25.) The instrument, therefore, can fulfil a double duty. As a large number of instruments require to be placed level, the recent addition to the tester is an advantage. Many accidents will be avoided by the use of this apparatus.

The author has found that red iodide of mercury and iodide of potassium, dissolved in glycerine, is a compound which serves well for a pole tester. Glycerine, having a high resistance, permits of the two pieces of

metal employed for the test being placed within an inch of one another for a pressure of 100 volts. To give an idea of the quantities used: to 1 oz. of glycerine add about half a teaspoonful of each of the iodine compounds; to accelerate the dissolving, place in very hot water the vessel containing the liquid and stir with a glass rod. It must be borne in mind that this compound is very poisonous. Blotting-paper, damped with the liquid, may also be used as a pole tester. The ends of the two wires to be tested are placed upon the paper about an inch apart. That wire which produces discoloration will be the negative. A good solution may also be obtained by omitting the red iodide of mercury. This is mentioned because some may find a difficulty in using the mixture of the two iodides.

Since it is imperative to start charging directly the cells have been filled with the electrolyte, and to continue the process till the liquid sparkles sharply (or, as it is generally termed, "boils," or "gases"), it is better not to fill up till everything is ready. The strength of the acid solution depends upon how far the process of forming has been carried, and the better the plates are formed the greater the advantage to the customers; otherwise a long charging has to be given before any real storage commences. The general reason assigned why plates are not sent out fully formed is that the liability of the paste to fall out during transit is reduced.

Authorities differ as to what strength the solution should be. Acid too weak, or too strong, destroys the plates. The E.P.S. cells have the sulphuric acid mixed with water till the s.g. is 1.170, and when the cells are charged the s.g. rises to 1.200 or 1.210. With the

porous-lead type of cell, such as the Crompton-Howell the s.g. of the acid may be put in somewhat stronger.

With the unpasted plates it is advisable that the electrolyte should never be denser than 1·20. Should it become so, water must be added. It may be interesting to many readers to know the percentages of concentrated sulphuric acid and of water in every 100 parts for various specific gravities. This information is given in the following table :—

Sulphuric Acid. (Per cent.)	Water (Per cent.)	Specific Gravity of Mixture.
50	50	1·398
47	53	1·370
44	56	1·342
41	59	1·315
38	62	1·289
35	65	1·264
32	68	1·239
29	71	1·215
26	74	1·190
23	77	1·167
20	80	1·144
17	83	1·121
14	86	1·098
10	90	1·068

It is best to purchase the acid already diluted. Pour sufficient into each cell to cover the plates completely, and within half an inch of the top edge of the cell. After filling, the s.g. of the liquid falls considerably, but on charging rises again. When an accumulator is left at rest for several weeks, the positive plates are apt to get into bad condition, and not unfrequently the negatives also. This trouble can almost be entirely remedied by doctoring the electrolyte. Any one of the following substances may be added, a small quantity

to every cell:—potassium sulphate, sodium sulphate, caustic soda, or common washing soda. Oxalic acid also is now found to be of service. In the case of washing soda, the active principle is the caustic soda, which is always present in the commercial samples. The author prefers using the caustic soda or sodium sulphate, which has met with better success in his hands than have the other substances mentioned. The proportion which he uses is 1 oz. by weight of solid caustic to 5 gallons of the electrolyte; but it must be added in the form of solution, say 1 oz. of caustic to 5 oz. of water. Any substance added to the electrolyte must be poured into the cells at the conclusion of the charging and before the engine is stopped. When the sodium sulphate is employed, the crystals must be dissolved in hot water, and about one ounce by weight of crystals added to every gallon of electrolyte.

If any of the other chemicals named should be employed, about 1 oz. by weight, in the solid, to 1 gallon of electrolyte should be used.

When the addition of any of the above-named chemicals is made, effervescence usually takes place (especially with the caustic soda); but this is of no consequence. The effervescence is due to carbonic acid being given off, the result being that a certain amount of the acid is neutralised, and the s.g. of the liquid is somewhat lowered. Therefore, the E.M.F. of each cell is slightly reduced. Occasionally it will be found necessary to add an extra cell to the accumulator in order to obtain normal pressure; but this will rarely be required. After a good charging, the accumulator can be left to itself for many months without injury to

the plates ; which is a great convenience to the majority of users. Caustic soda should not be touched with the hand, as it burns the skin, while to clothing it is most destructive. Any weak acid serves as a neutraliser. The caustic soda mixing with the electrolyte immediately becomes sodium sulphate. As the latter is cheap compared with the price of the former, most persons use it ; and it answers quite as well. The solid sulphuric acid referred to on page 63 contains soda, so that when this substance is brought to the correct specific gravity by the addition of water, a "doctored" electrolyte is made at starting.

When a battery has been in use for a considerable time it is frequently found that the upper parts of the plates are not in good order. Under these circumstances, when caustic soda is added, the powerful chemical action, which takes place at the moment it reaches the electrolyte, where the upper parts of the plates are situated, appears to improve the plates to a greater extent than when the sodium sulphate is added ; and this is the reason why the author has so often employed caustic soda in preference to the cheaper chemicals. It is desirable to charge a battery thoroughly, and to use it for a period of two or three months before doctoring the electrolyte. There are many persons who believe that the addition of any of the chemicals named is productive of no advantage ; on the other hand, a large number of users hold contrary views. The writer's experience is decidedly in favour of the addition. Mr. Robertson's recent researches show conclusively that the presence of soda or potassium is a distinct advantage.

A good plan is to place an acidometer in every cell. By this means the specific gravity *i.e.* density of the

liquid, in each cell can be observed, and the variations noted during the charging and at other times. In fact, there is at present no other practical and reliable method for ascertaining the condition of each cell. The ordinary form of an acidometer is a sealed tube containing a paper scale, weighted at one end so that it floats upright when placed in a liquid, and its general form is that shown in Fig. 26. The weight is so adjusted by the makers that the upper part of the tube, with a portion of its scale, projects above the level of the liquid. If the liquid becomes denser, *i.e.*, of greater specific gravity, the acidometer rises, so that more of the tube and its scale is exposed above the liquid, and *vice versa*. Consequently, by noting the position of the surface of the

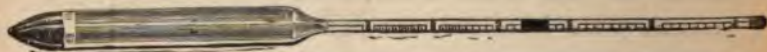


Fig. 26.—Acidometer

liquid in reference to the scale, and taking the reading, a definite idea of the s.g. can be ascertained. It may be mentioned that specific gravity (generally written s.g.) means the comparison between the weight of any substance with that of pure water at a temperature of 15° C. For instance, a solid, or liquid, of a s.g. 2, means that it is twice the weight of water.

Mr. Hicks has devised a very pretty acidometer, consisting of a tube containing four flattened glass bulbs of different colours. One or more of these bulbs rises to the top of the tube, according to the specific gravity of the electrolyte, which finds its way into the tube through numerous holes. (See fig. 27.) It will be observed that the top is turned hook fashion, in order to hang over the edge of the cell and to prevent it from

falling to the bottom. Thus, when all four bulbs are at the top the s.g. is 1.200; when all are at the bottom, the s.g. is below 1.150; when one is down and three are up, the s.g. is 1.190, and so on. It is, therefore, only necessary to notice the colour of the lowermost bulb which is up, each colour representing a given specific gravity. These bulbs can be manufactured to rise at any desired specific gravity. It may be observed that, if the hooked part of this acidometer is left too long, and fluid gets into it, there is the possibility of a small amount of liquid syphoning over. This having proved a source of trouble to some users, it is thought best to point it out, so that, if the hook in any case should be found



Fig. 27.—Hicks's Acidometer.

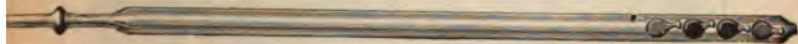


Fig. 28.—Hicks's Pipette.

too long, it may be shortened before any harm is done, or else kept free from liquid.

A pipette is constructed on the same principle, and for a similar purpose. (See fig. 28.) Its method of employment is the following:—The tube containing the coloured bulbs is dipped into the liquid; the finger is placed over the open top of the tube, which is then lifted out, being full of liquid, the latter being retained by atmospheric pressure. The specific gravity of the liquid can be observed by the position of the coloured bulbs, in the same way as with the acidometer.

The Holden type of acidometer is shown in fig. 29. The floating portion is made of ebonite suitably

weighted at the lower end. The scale is attached to the connecting strip of one of the sets of plates, and indications

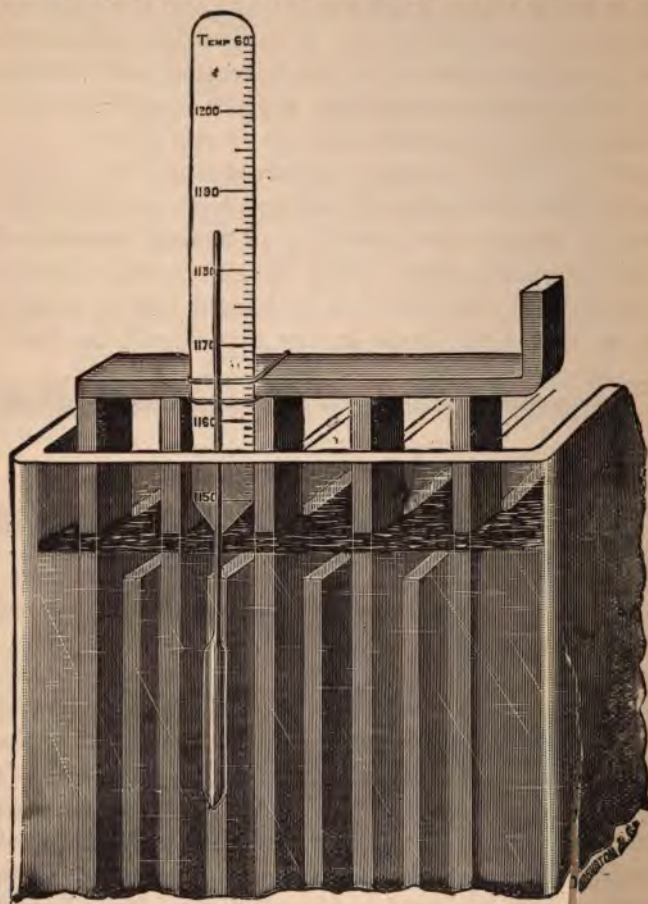


Fig. 29.—Holden type of Acidometer.

are read from the position which the upper end of the float occupies in respect to the markings upon the scale

which, as may be noticed in the plate, reads at 1.185. The best way to attach the scale is by an indiarubber band, or a piece of lead wire.

The author believes that he was the first to observe the state of the plates by means of an acidometer and to employ a modified argentometer, such as is used by photographers for ascertaining the strength of nitrate of silver solutions, long before acidometers were thought of, and at a time when absurd devices were being brought out for estimating the amount of charge existing in a cell. He was also the first to recommend the use of cover glasses.

Over the top of each cell is now placed a curved glass slip, the convex face towards the liquid. These curved glasses do not, in most cases, cover the whole of the opening of the pot, because the lugs of the plates project above the cell. With some builds of sections the glasses may be laid on the tops of the connecting strips. With others flat glasses resting on the lead bands of the sections, and touching the liquid, are employed. This is the case with the **K** type. Any spray driven off is collected on the glass and runs back into the cell, thus assisting to keep the level of the liquid constant and the room free from acid fumes.

Various other devices have been brought out from time to time to keep down the spray. Messrs. Drake & Gorham have employed pounded cork, rendered water and acid proof by being soaked in oil or some similar substance. Another device consists of covering the whole surface of the liquid with small floating blown-glass balls, each about the size of a pea. The cork is open to the objection that you cannot see the plates from above, and the glass balls are undesirable, since

they continually break, and a quantity of broken glass in the pot is the result. In the early days of accumulators, petroleum or oil used to be floated on the surface of the electrolyte, which, within a short time, became muddy. Whatever the substance may be that is floated on the surface of the liquid, it must necessarily impede the use of an acidometer; and furthermore, the greater the freedom permitted for gas to escape, the better the plates are kept in order. Glass covers are, therefore, to be preferred from every point of view. In those cases where powdered cork or any other floating material is employed to keep down the spray, a clear space may be obtained for the use of an acidometer by placing on the surface of the liquid a small ring of wood or other light substance which will float, and with a hole large enough to pass the acidometer through. It will be evident that this hole may be kept free of all impediments.

The battery is now ready to start charging, and this should be commenced without delay.

Before proceeding to the next chapter a description of the Broomhill accumulator-house will not be out of place, since it has been erected as a model. Completed now more than ten years, its practical convenience has been amply tested and proved, so much so that it has been copied in other installations. A representation of the room is given in the frontispiece. The other frontispiece shows the Broomhill engine-house.

The structure is about twenty-eight feet long, by eleven feet wide, and thirteen high. The roof is flat, and in the centre there is a cast glass dome, four feet in diameter. The north end of the roof has a lean-to light five feet long, extending the whole width of the room, and facing the north. This arrangement never allows

the direct sunlight to fall on the glass cells, which is frequently the cause of their breaking. In the south wall there is a large window, opening like a French casement, for ventilation; but shrubs are planted outside to keep off the sun's rays. There is ventilation also in the roof; and this is obtained by the glass dome being slightly raised above the "lead flat," so that there is an air space allround. There are two doors at the north end, facing east and west, to admit air from the outside when desired. The shelves run north and south, and are two feet from each wall, leaving a good space between the cells and the wall sufficient for a man to pass and to work. The two rows of shelves have four tiers in each, with a broad alley down the centre. The top tier has been added since the drawing in the frontispiece was made. The shelves are two and a half inches thick and nine inches broad, and rest on bearers screwed and let into standards, six on each side, two inches thick, eight inches wide, and about eight feet high. The tops are tenoned into pieces of wood, which bridge over the two-foot pathway, and are let into the wall. Bolted through each wall, running north and south, there is a piece of timber which these cross-pieces are let into and screwed; thus, there is no possibility of the shelves falling inwards or outwards. The bottoms of the standards rest on a chequered blue vitrified brick floor, laid on concrete. The shelves, being broader than the standards, have the ends mortised in such a way that, though loose on their bearers, it is not possible for them to shift when once laid in their places. The distance between them is sufficient to enable the cells to stand with twelve or fourteen inches to spare, thus allowing an easy examination of the plates to be made from

above. There are zinc plates nailed on to the edges of the shelves, having numbers painted upon them in black on a white ground, in order that each cell may be identified. Each cell-board carries a label, stamped with figures giving the date of its erection. The floor is slightly inclined, and, being chequered, is easily washed down without remaining wet under foot; and there is a grating at one end to carry off the water. There are also a sink and a water tap in the room, and a small place adjoining (some six feet square) for an acid tank and other requirements strictly necessary for an accumulator. The walls are cemented, the ceiling is match-boarded, and all woodwork sized and twice varnished. Two fifty candle-power lamps, let into the ceiling, light the room, the switches being on the shutting post of the entrance door. There is a large Wenham gas burner, should it ever be wanted; also a gas-soldering apparatus; and a portable lead-burning arrangement devised by Mr. Stephen Holman, of Messrs. Tangye. A wall-connector is provided to enable a portable lamp to be used. This is most useful in an accumulator-house for the examination of the sections, whenever required. All windows and skylights are barred, to keep out intruders of a badly-disposed kind. The design of the shelf-racks is such that eight feet from the floor all is clear, even the lamps being above the ceiling line. This space allows an overhead half-ton traveller to run north and south, the rails being laid upon timbers borne by the cross-pieces between shelf-standards and wall. There is a special cradle with adjustable counterpoise, so made that the cells may be lifted with perfect ease without requiring the point of suspension to be over a cell. The pulley blocks and

traveller were made by Messrs. Tangye, and the cradle was devised at Broomhill. So successful is this lifting arrangement, that in a moment one man can move a cell filled with liquid from one given point to another, and to any level. For the sake of rapidity, it is more convenient to have two men—one to look after the cell and the other to move the traveller and work the blocks.

Each set of shelves, running north and south, holds 52 cells, 23-plate section size—104 in all. At every third cell there is an upright standard, and between each cell a loose prop is placed betwixt shelf and shelf, to prevent any tendency of the wood to bend under the weight. The bottom shelf is six inches from the ground. At the south end the shelves are returned sufficiently for a cell on each row, and leaving a passage through to the south window. Consequently, there is room for 112 cells, but two places at the southern end are unoccupied; hence 110 cells are installed. All cells rest on insulators, and are connected one to another by special cast-iron and gun-metal couplers, each having an attachment to take a cable. The latter arrangement is most useful in case of need, such as for cutting out one or more cells at any time, and for experiment. The top (fourth) shelf was added to meet the requirements of the latest form of cells, which are larger in size, though containing the same number of plates, as shown in the drawing. Only three of the more recent types can be placed between standard and standard, instead of four; and so the extra shelf space became necessary. Against the north, and a small portion of the east and west walls, there are also shelves which carry twenty-one cells, employed in connection with the counter E.M.F. governor.

The two batteries of 55 cells are, at the present time,

March 1893, composed of the following kinds of cells. Accumulator 1 :—(West side.) 22—"1888" E. C. C.—8 author's, old type E. C. C.—20 author's, new type E. C. C.—2 Crompton-Howell—2 Epstein—1 K E. P. S.—Total 55 cells. Accumulator 2.—(East side.) 31 K E. P. S.—16 author's, old type E. C. C.—2 author's, new type E. C. C.—2 Johnson & Phillips—4 Crompton-Howell.—Total, 55 cells. In all instances the size of the sections is so chosen that they may be worked in series on equal terms.

The counter E. M. F. cells are the E. C. C. 1888 type and those of the author's latest pattern.

There are other cells in position for experimental and for testing purposes.

The frontispiece shows the arrangements, also a cell suspended in the cradle to illustrate the method of using the latter.

In the Broomhill Accumulator House 110 cells can be unpacked, set up, and started charging in ten hours by six men—provided the sections are sent ready made—a result which probably exceeds the fastest work on record.

CHAPTER III.

CHARGING.

THE first charge differs in some respects from charging in the general way. There should be a steady run of thirty hours without stoppage, if possible, or not less than ten hours a day during three successive days, for the size of cells commonly in use. The electrolyte will then commence to boil; it will have a milky appearance, due to the quantity of gas bubbling through the fluid, and, if the acidometer-reading be observed, it will be found that the s.g. has risen to about 1.200, or even higher.

The word "boil" is meant to indicate not a rise in temperature (although, in fact, there is a slight rise), but simply the appearance of a liquid in that state. The charging must be continued till every cell boils in an equal degree. The current should be kept well within the permitted maximum. For some weeks, probably, there will be a difficulty in getting the cells into an equal state, and long charging alone will secure this. Over-charging does no harm whatever, unless the current is too great. If one particular cell, here or there, will not boil, it is best disconnected from the circuit during the hours of discharge, but it must be reinstated when

charging is started. Should this fail to attain the desired result, the plates must be examined. Every cell must be separately tested for E. M. F., which should not be less than 2 volts; if under 1.9 volt, the cell has been discharged as low as is consistent with safety. When nearly charged, 2.1 to 2.2 volts per cell will be registered. At the conclusion of a charge, each cell, for a short period of ten to fifteen minutes, gives as much as 2.3 to 2.5 volts. Then the E. M. F. drops to near the normal, and, after a slight discharge the usual E. M. F. will average 2 volts per cell, as nearly as possible. These tests are taken on open circuit—that is, when the cells are neither charging nor discharging.

There are two convenient pieces of apparatus—both made by the Electric Construction Corporation—for ascertaining the E. M. F. of individual cells. One instrument consists of a 2-volt lamp mounted on a small rod of ebonite, which has the end tipped with a brass point, the latter being in electrical connection with one loop of the lamp. The other loop is continued to a terminal, with a piece of wire attached, ending in a brass cap with a point on it, which serves as a protector for the lamp when out of use. It is necessary, when testing, to place the brass point on the ebonite rod upon one strip of the plates in the cell, and the pointed cap at the end of the wire upon the other strip. The plates are now short-circuited through the lamp, and by its brightness the condition of the cell may approximately be ascertained. It is to be regretted that the Corporation no longer supply this convenient little pocket apparatus, the reason being, no doubt, the difficulty of being able to obtain a good 2-volt lamp; but probably the instrument could again be supplied, if ordered.

The other instrument is a more scientific one, and consists of a small voltmeter, very portable and well protected (see fig. 30), which registers from 2 to 4 volts on a very open scale, graduated to tenths, and is dead-beat. Two wires leave this apparatus and are attached to a cylindrical wooden rod having roughened brass tubes upon it at each end. One wire is connected to each piece of tube, and the tubes are insulated from one



Fig. 30.—E. P. S. Voltmeter, for testing cells. Made by the E. C. C.

another. When used, the rod is simply laid across the cell with one hand, so that one brass tube rests upon each strip (the length of the rod being suitable for this purpose), while the voltmeter is held in the other hand and observed. Failing a good connection between the tubes on the rod and the lead strips, it is only necessary to move the rod file-fashion, when the roughness on the tubes will clean the lead and establish good contact. Messrs. Nalder, the Walsall Company, and other firms have

now followed suit in making neat little voltmeters for this purpose. Fig. 31 is an illustration of the Walsall Company's voltmeter, graduated by tenths up to 4 volts. There are no permanent magnets in it, and the current acts against the force of gravity.

Fig. 32 shows Messrs. Drake & Gorham's contact-maker, to be used in connection with these voltmeters. The two copper U pieces are for attachment to the

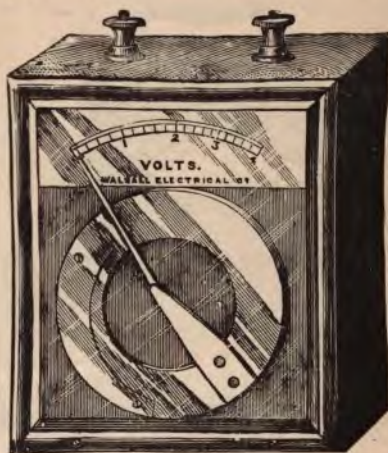


Fig. 31.—Walsall Voltmeter.

voltmeter. The point at the end of the rod and the one placed upon it are pressed into any part of the positive and negative portion of the section under test.

The E. P. S. Co. make plates of various sizes to meet every requirement. For electric lighting and traction work the plates in general use are practically of one size, no matter what the types may be. The sections are usually made with 15, 23, or 31 plates in each, but there is no reason why any other number of plates should

not be chosen. Cells containing two or more sections are also supplied.

The remarks which now follow mostly apply to all types of lead plates, except where it is evident from the context that only the pasted grids are referred to. For pasted plates, the proper charging rate is 6 ampères per square foot of positive plate (not surface). Thus, in a 15-plate cell, which contains 7 positives, 20 to 22 ampères should not be exceeded for charging; in the 23-plate size, with 11 positives, 33 ampères is the maximum

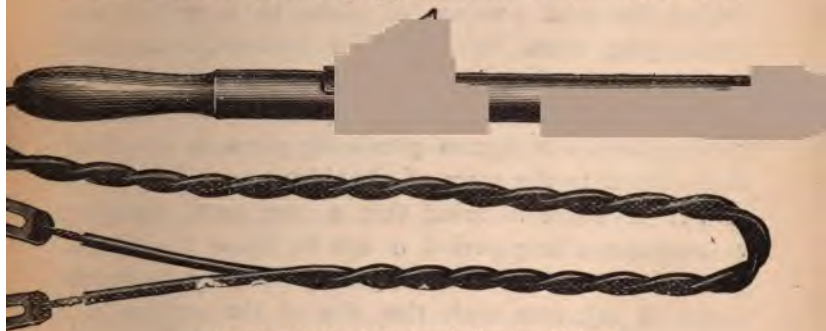


Fig. 32.—Drake & Gorham's Contact Maker.

charging current. For the usual size of plate (till recently termed L) the rate may be expressed by saying that 3 ampères per positive plate is the charging current. If a much larger current is passed, the cells boil as if they were fully charged, showing that the surface of the plates is insufficient for the current to act upon; and the excess of current does its work by simply decomposing the water of the electrolyte, creating volumes of gas and heating the liquid. Independently of this waste, the plates are injured. These figures also apply to the discharge.

In the most recent types the grids and paste have been

so much improved that it is possible to charge without injury a 15 and a 23-plate cell as high as 30 and 46 ampères respectively, or an increase of at least 30 per cent.; and when these sections are built up, in the manner of the K type, the charging current may be still further increased, because the action over the whole surface of the plates is more equal. With recent plates, the charging and discharging current may be taken at a fraction over 8 ampères per square foot of positive plate; or this may be stated in a more general way by taking the total number of plates in a section and multiplying them by two. For instance, a 23-plate section may be charged and discharged at twice 23, *i.e.*, 46 ampères, without injury to the plates. The object of stating the lower figures previously given is to afford information to the users of the older types. It must always be borne in mind that a very small charging current over a long period is apt to injure the plates. A current so small as 2 or 3 ampères may be considered as injurious with the size of the section just named. To put this minimum current in the form of a rule, it is advisable that the charging current should not fall below one-tenth of the maximum current; and the injurious current may be taken as the number of plates in a section divided by ten.

The positive plates are about 8 by 9 inches, the negative plates slightly larger; and both are approximately a quarter of an inch thick. The area of each side of every plate is, therefore, as near as possible half a square foot.

The E.M.F. of the charging current at starting should be, under ordinary circumstances, about 5 per cent. higher than the normal E.M.F. of the

battery. If the battery has been much discharged, the difference of pressure should not exceed 2 per cent.; otherwise too large a current may flow. After a short time—which may vary from a few minutes to half an hour—the E.M.F. of the charging current may be raised to 10 or 15 per cent. above the normal E.M.F. of the battery. This state of things may continue till the charging is nearly completed, when there is a rapid rise of pressure in the battery; and it may be necessary (if it be desired to keep the charging current constant) to raise its E.M.F. 30, or even 40 per cent. above the normal pressure of the battery. For instance, if a battery were to consist of 50 cells, its normal pressure would be 100 volts. If it be desired to keep the charging current constant, the battery being assumed to be in good order, the E.M.F. of the current at starting should have a pressure of 102 or 105 volts, according to the degree to which the battery has been discharged. In about half an hour the pressure of the charging current should be raised to 110 volts, or more, till within an hour of the end of the charge, when the pressure should be continually raised till it reaches from 130 to 140 volts.

Where no provision exists for keeping the charging current constant, it will be found that if, at starting, it is normal, then, as charging proceeds, the current grows less and less; consequently, the time required to run in such cases is very much longer than when the current can be kept constant. If the charging current is very small, say one-tenth of the maximum, then, however long the run, the cells do not appear to charge; unless they be in perfect order and the insulation exceedingly good, which is rare, and this proceeding, as has been already

stated, is to be deprecated. So much for the practical side of the charging question, as regards pasted plates and many kinds of plain lead plates.

For cells containing any type of lead plate with dilute H_2SO_4 for the electrolyte, the result of charging is to convert PbSO_4 on the positive plates into PbO_2 , which change is thus effected. SO_4 goes to the electrolyte in exchange for O ; the liberated H_2 of the water (H_2O), joining with the SO_4 , forms H_2SO_4 . The next action is, another atom of O joins the PbO , making PbO_2 ; and the liberated H_2 of the H_2O , going to the PbO of the negative plate, forms $\text{Pb} + \text{H}_2\text{O}$. The first and final chemical composition of plates and of the electrolyte is known, but the chemical equation or equations, showing the change from the first to the final state, though given in many ways by able hands, may still be regarded as problematical. No attempt will, therefore, be made to give equations which might lead to error. The following three expressions convey a general idea of what takes place :—

POSITIVE.		ELECTROLYTE.		NEGATIVE.	
1st stage	PbSO_4	...	$\text{H}_2\text{SO}_4 + \text{H}_2\text{O}$	...	PbO
2nd	„ PbO	...	$\text{H}_2\text{SO}_4 + \text{H}_2\text{O}$	...	PbO
3rd	„ PbO_2	...	$\text{H}_2\text{SO}_4 + \text{H}_2\text{O}$	...	Pb

The first stage indicates the discharged cell. The second stage shows what might be termed the rational change which takes place, though in all probability a number of equations would be necessary to express what really happens between first and last states. In the second stage molecules of water have been removed from the electrolyte and an equal number of molecules of H_2SO_4 added, thus increasing the strength of the acid solution. The s.g. of the electrolyte may decrease slightly in

stage 3. Hence we see why the s.g. of the electrolyte increases as the charging advances. It will also be noticed that the H_2SO_4 originally put in appears to play no part whatever beyond making the water a good conductor; yet, if no H_2SO_4 has been added in the first instance, the chemical actions are not quite the same, and the plates are soon injured by secondary reactions, giving at the same time a lower E.M.F. Water is a very bad conductor, and therefore this liquid could not possibly be employed by itself under any circumstances, since the internal resistance of the cell would be so high that but little energy could be obtained in the outside circuit. There is, however, an additional chemical action during charging, for gas is given off at all periods of the charge, first from the positives only, and later from the negatives. This tends to prove that water is being decomposed, the O of which does not unite with the paste of the positives, and that H is absorbed in the negatives, or goes into chemical combination with them for a time, or forms some new substance in the electrolyte; but when the end of the charging approaches, and the negative can take up no more gas, H is given off from these plates. This action is evidently a waste of energy.

There is far greater loss with storage than is generally supposed, notwithstanding that many eminent men have shown great efficiency in laboratory tests. For practical purposes such tests are worthless, and no one is recommended to expect more than 65 to 70 per cent. of efficiency in the long run. These are approximately the figures obtained from eight accumulators over extended periods, as well as from a large number of isolated cells. There is no doubt that, under exceptional conditions, the efficiency may apparently be raised

another 10 per cent. ; but to produce this so much care and attention are requisite that in practice it is better to consider practical results than economy only to be obtained at the cost of much labour, which means expenditure.

In getting current through the battery in the first instance there must be a loss of about 15 per cent., viz., the average difference between the E.M.F. of the charging current and the E.M.F. of the accumulator. Power also is required to get it out, if such an expression may be allowed. There is loss from leakage due to local action, to cells being in bad order at times, and many other causes which do not exist in the usual laboratory tests. The loss may be regarded entirely as "pressure loss," for to all intents and purposes the number of ampère hours put into a battery can be got out of it.

A very interesting, as well as memorable, paper on the subject of secondary batteries was read before the Society of Arts in 1891 by Mr. Robertson, and it is well worth perusal. (See *The Electrical Engineer*, December 4th, 1891.) If the most important part of the paper—that dealing with chemical questions—is correct, as it certainly would appear to be, many enigmas are explained by the writer: such, for instance, as the cause of bad sulphating; why the addition of sodium and potassium is beneficial; why the E.M.F. near the end of the charge rises so rapidly; and why, when a cell is almost discharged, its E.M.F. drops from nearly normal to zero without gradual fall. Mr. Robertson also proves how very complex the chemical equations must be in order to express what takes place in a secondary cell.

The following is a *résumé* of the chemical portion of the paper:—

Bertholet discovered persulphuric acid, $\text{H}_2\text{S}_2\text{O}_8$, in the year 1878. He showed that it is the primary product of the electrolysis of sulphuric acid solutions, and that hydrogen dioxide is really due to the action of this body on the acid. The products of electrolysis vary with the strength of the acid. If the density is 1.300, practically no hydrogen dioxide is formed, while below and above that strength it is found to be present in varying proportions. High current density, under electro-negative condition of the electrodes, favours the formation. Persulphuric acid is an unstable body and decomposes as soon as the current, which has given rise to it, is stopped, hydrogen dioxide being formed during its decomposition, unless the sulphuric acid is too dilute. Hydrogen dioxide also is unstable when concentrated, but a weak sulphuric acid solution of it is comparatively stable, and the less hydrogen dioxide it contains the more stable it is; consequently, this substance is found in small quantities long after the persulphuric acid, which gave rise to it has disappeared. Subsequent workers have on most points confirmed Bertholet's conclusions. During the time that the cells are charged, persulphuric acid is present, and during discharge the hydrogen dioxide gradually increases; while in a cell which has been at rest for some time, practically hydrogen dioxide alone is to be found. Experiments showed that, although persulphuric acid itself does not reduce peroxide of lead, hydrogen dioxide does so; and this explains why cells when resting become discharged. In an ordinary cell of the size generally in use, there is usually sufficient hydrogen dioxide to undo the work of from one to two

hours' charging if the cells are left to rest, and sulphating may result ; but clearly when the battery is in use no harm occurs, since the peroxides have been continually broken up with each reversal of the current. It was found that the addition of sodium sulphate to the electrolyte had but little effect, unless it was added during the time charging was proceeding ; and it was noted that where this chemical was introduced the amount of persulphuric acid was increased. Consequently, a larger proportion of hydrogen dioxide will be found subsequently than in a cell where the addition had not been made. This result might have been anticipated, since the persulphuric acid is not injurious to the plates with the larger quantity to be found under the conditions just named ; the cells might rest for a longer period without harm, although a time must arrive when, in consequence, there will be excess of the hydrogen dioxide and the sulphating will proceed as rapidly, or more rapidly, than in a cell to which the sodium sulphate has not been added. There is strong evidence to show that certainly many months must elapse before all the persulphuric acid is decomposed.

Experiments, made to ascertain what would be the action of the presence of hydrogen dioxide in the electrolyte by adding a small quantity of this substance to the liquid, prove conclusively that the E.M.F. was much lower, or even became reversed. But the addition of the hydrogen dioxide to the peroxide paste increases the E.M.F. It would thus appear that towards the end of the charge the hydrogen dioxide is formed at the positive plate, and towards the end of the discharge hydrogen dioxide becomes diffused through the acid and finally is present on the negative plate. Lastly, the

rise of E.M.F., which is usually found to exist when a discharged cell is permitted to rest for a time, may be due to a decomposition of the hydrogen dioxide having taken place on the negative plates. Mr. Robertson concludes that the majority of the troubles, which pursue the users of batteries are, owing rather to the mode of using than to faulty manufacture; which conclusion the author arrived at many years ago. There can be no doubt that the improvements in future will take the form of a modified electrolyte, which, according to Mr. Robertson's investigation, must be of such a nature as to prevent the formation of, or at once to break up, any deleterious substance which may be formed during the charge or discharge of the battery. It is satisfactory to find that the writer of the paper referred to confirms the principle now so universal in practice, which is that in cells containing acid having a specific gravity of less than 1.200, one per cent. of sodium sulphate, or of some equivalent substance, proves beneficial, especially when the cells are at times left to rest. On the other hand, he shows that when the acid density is greater, there is less need for doctoring, because the circumstances are more favourable to the stability of the persulphuric acid; in which case the addition of sodium sulphate might be prejudicial. But it must be remembered that in practice, for the good of the plates, the electrolyte is rarely, if ever, allowed to rise much above s.g. 1.200. Therefore, it may be concluded that the addition of sodium sulphate is always advantageous.

Mr. Robertson has also made an examination to ascertain the cause of the electrolyte discoloring to a purple, which it frequently does. His tests, which were confirmed by spectrum analysis, indicate the presence of

potassium permanganate. Of course, in some cases discoloration may be due to other substances depending very much upon the nature of the lead ore from which the plates were made.

If the strength of the acid solution is above 1.700, bad sulphating rapidly ensues, with great loss of capacity, although giving a good E.M.F.

The level of the liquid in the cells must be kept constant. To effect this, the first few additions of fluid should be H_2SO_4 s.g. 1.150 or 1.170; after this only water, unless it is found on completion of the charge that the acid is below the normal strength, in which case fill a few times when necessary with acid solution, as already mentioned.

Two phenomena, which have frequently puzzled the users of cells, are worthy of mention. One is that when a new battery is erected, on its receiving a considerable charge, the s.g. of the electrolyte is found to have risen, as is usually the case. This increase of the s.g. after standing a few days, or even hours, is partly or wholly lost, a state of things which may continue for many chargings. When this does occur, it is a proof that the plates have not been very fully formed, and chemical action goes on within the plates while the battery is standing. The second phenomenon is that at all times when charging is first started, there is a slight fall in the density of the liquid, which is soon recovered. This is due to some peculiar chemical action set up at the commencement of the charging. It is assumed in the first case that no discharge has been taken, and in both that the plates are in good order. No disadvantages attach to these phenomena.

From careful chemical analysis, made by Mr. G. H.

Robertson, it would appear that only one half of the PbSO_4 is converted into PbO_2 in a fully charged plate. For this there may be two reasons: (1) that there is some mechanical cause why the whole of the lead sulphate is not converted into dioxide; and (2) that the negative plates have run down and become neutral for further work upon the positives. From recent investigations both reasons would appear to apply, for, if the particles of paste of a discharged positive plate be examined, they will be found to consist of granules of PbSO_4 and to contain nuclei of PbO_2 ; thus showing that these nuclei have become isolated from the electrolyte, and therefore lost for practical purposes. Also the discharged paste occupies a larger space than when charged. This in itself may tend to render portions of the plate waterproof, by blocking up all the interstices. It is likewise found that the negatives exhaust themselves sooner than the positives, which may be easily demonstrated by taking the positives from a cell that is exhausted and putting them into another containing a set of charged negatives. It will then be found that a very considerable further discharge may be obtained from the plates. But in no case does it appear possible to reduce the whole of the lead sulphate to lead dioxide. In making the experiment just mentioned, it is advisable that the positives under test should be put into the cell containing the negatives, and not *vice versa*, because a chemical change takes place in the negatives when exposed to the air. In practice, it is usual to put in the positive plates a considerably larger quantity of PbSO_4 than theory would demand. The object aimed at is that only a small proportion of the paste should be converted into lead dioxide, the advantage being that the paste is

stronger and less liable to fall away from the grid. It is thus evident that the paste holds in the positives better in the discharged state than when charged, and for this reason makers require their customers to finish forming the plates upon arrival at their destination. When a positive plate is discharged till the paste contains about 30 per cent. of PbO_2 , it is found there is very little E.M.F. Chemical action starts from the grid to the paste. It is, therefore, important that there should be an intimate connection between the two. Many difficulties with the negative plates have been owing to this cause, as their paste shrinks away from the grid. An improvement has recently been made in the shape of the grid, whereby the shrinkage assists in forming a better connection instead of separating. Some attribute this shrinkage to the litharge being impure and containing sulphate. Many consider that, when it contains traces of sulphate, there is less chance of these plates blistering. Evidence is insufficient at present to form a definite opinion. Many makers of pasted plates prepare the grids in the Planté fashion, to secure a better contact between the paste and the grid. It is the present practice to dry the plates before they are formed in order to secure harder paste, though this process will require longer time. The positive plates require about eighteen hours to form, and the negatives about six times as long. It is usual, therefore, to form the positives and negatives separately; but the time required is longer if the operation is not continuous.

To account for the variations of the E.M.F. in a cell, an interesting paper written by Dr. Gladstone and Mr. Walter Hibbert, was read at the Institution of Electrical Engineers on May 12, 1892. In this paper an attempt

is made to show that the cause is due to the formation of layers of different densities in the electrolyte, and certainly the writers go very far to prove their case. It is probable that the explanations given by Mr. Robertson, as well as by Dr. Gladstone and Mr. Hibbert, are all more or less correct; and the chemical actions as explained by them may both contribute to the result. The following is a quotation from the paper last referred to, which in part indicates the methods employed by the writers in arriving at their conclusions. The table is also a useful one for reference.

"The following figures, calculated from Kohlrausch's results, will give an idea of the variation :—

"RESISTANCE OF SULPHURIC ACID SOLUTIONS.

% HO_2S_4	Relative Resistance.
2'5	6'73
15'0	1'33
30'0	1'00
50'0	1'35
71'0	3'79
95'0	7'29

"Hence we should expect that, if the acid against the working surfaces of the plates is being concentrated during charge, or greatly weakened during discharge, there would be a marked increase in resistance."

The following tables are copied from an able paper, read before the Society of Telegraph Engineers and Electricians, on March 10th, 1887, by Mr. Desmond Fitz-Gerald, and they are given here, as they may prove of interest :—

TABLE I.
STORAGE CAPACITY OF VARIOUS SECONDARY CELLS.

Name of Cell.	Per lb. of Pb.		Per kilo of Pb.		Authority.
	Foot lbs.	Watt hours.	Killigram metres.	Watt hours.	
Planté	12,000	4.52	3,664	10	Howard (?) Hospitalier.
Faure	18,000	6.78	5,485	15	
E.P.S. L plates	48,000	18.09	14,600	39.8	
„ R „	36,080	13.6	11,010	—	
„ S nominal... 22 lb. cell.....	{ 31,800	12	9,540	26	Fitz-Gerald
Elwell-Parker... (Old form)	{ 6,633	2.5	22,018	5.5	Prospectus
Lithanode Battery... (Old form)	{ 39,798	15	121,110	33	Fitz-Gerald
Lithanode Battery... “ Union ” cell...	{ 47,170	17.8	14,671	39.16	G. Forbes

TABLE II.
WEIGHT PER HORSE-POWER HOUR CAPACITY OF
VARIOUS SECONDARY BATTERIES.

Name of Battery.	Elements only.		Cell complete.		Authority.
	Lbs.	Kilos.	Lbs.	Kilos.	
Planté	—	—	396	18.5	Reynier.
Faure	{ —	—	88	40	Faure.
„ (old model)	{ —	—	165	75	Sir W. Thomson.
„ (new model).....	—	—	198	90	Reynier.
E.P.S. L plates	{ —	—	133	61	
„ S „	{ —	—	134	60.4	Prospectus.
Reynier } Zinc positive	66	30	110	50	Reckenzaum
Reynier } Planté form..	50.6	23	135	61.3	Fitz-Gerald.
Lithanode battery.....	105	47.6	117.5	53.4	Tamine.
(Old form)	{ 42	19.1	76	34.5	Idem.
Lithanode battery.....	{ 42	19	70	31.5	Fitz-Gerald.
“ Union ” cell.....	{ 42	19	70	31.5	G. Forbes.

Mr. Fitz-Gerald doubts the accuracy of Mr. Howard's results, which he thinks are due either to error, or to the methods employed.

This well-known experimenter has recently made, in plates to be employed in secondary batteries, great improvements which largely increase their storage capacity. The improvements consist in treating the plates with magnesium sulphate, and in the method of constructing the plates themselves, by consolidation; the result being that the active material on their surface can be increased indefinitely without incurring any loss of its conducting qualities. These processes are patented. The author has the permission of Mr. Fitz-Gerald to describe an experiment, made by him, which indicates the result of the MgSO_4 (magnesium sulphate) treatment.

Experiment.

"Two couples (A and B) formed of lead plates with immersed surface $3'' \times 2''$; A in dilute sulphuric acid of s.g. 1.17; B in half-saturated solution of MgSO_4 .

"Couples charged for two hours, with reversals when gassing freely.

"B plates removed from MgSO_4 electrolyte and immersed in dilute H_2SO_4 (s.g. 1.17).

"Circuited consecutively on an electric bell (wire resistance 11.5 ohms). The following results were obtained:—

"A rang bell for 3.2 minutes.

"B " " 19.5 "

"The difference may be made enormously greater in favour of B."

The experimenter remarks that by this treatment

every pound weight of the battery has a storage capacity of 1.66 ampère hours, and a discharge of 10 ampères.

Mr. Fitz-Gerald, in the course of the discussion upon Professor Ayrton's paper on Secondary Cells, before the Institution of Electrical Engineers, gave some interesting information; and as his words cannot be improved, they are retained, as far as possible, in the following abstract:—

“ There would appear to be no particular reason why the metal lead should invariably be adhered to as the support for the spongy lead (which may be paste); and in many cases copper would seem to be decidedly superior to lead as a support for the active material in the negative plate. Local action, which would destroy the copper, may be all but entirely obviated by adding to the electrolyte almost any alkaline or soluble earthy sulphate. There is a general belief that the addition of washing soda to the electrolyte is beneficial. If true, this advantage is probably due to the fact that almost any soluble sulphate can form a double salt with sulphate of lead, which salt is more or less soluble. Sulphate of magnesia particularly exerts an extraordinary effect upon the electrolyte by reason of its solvent action on the sulphate of lead. If, for instance, you take dilute sulphuric acid and a half-saturated solution of sulphate of magnesia as the respective electrolytes of two couples, in which the electrodes are plates of lead, you will find, if you pass a current through these electrolytes until the elements of both the couples freely evolve gas, that, after a few reversals of the charging current, the plates immersed in the sulphate of magnesia will give a discharge, or will possess a capacity, some 30 to 40 times greater than

the discharge from the plates immersed in the dilute sulphuric acid."

Mr. Fitz-Gerald calls the litharge, or the plain lead, plate the positive; but the author keeps to the usual practice, as adopted by the manufacturers, in order to avoid confusion.

The more complex salts of lead electrolyse more easily than the simple salt PbSO_4 . The question naturally arises: Why is it so troublesome to charge a battery which has been much exhausted, in which state it is almost certain that the positive plates have upon them many of the higher sulphates of lead? The probable explanation is that, lead sulphate being a bad conductor, the current cannot do its work effectually. This fact may account for the existence, in a positive plate, of far more paste than is actually required to serve a useful purpose, since, if the whole of the paste, which can be reached by the electrolyte, were to be converted into sulphate upon discharge, it might be found absolutely impossible to convert the sulphate back into dioxide.

Professor Crookes has pointed out that H_2SO_4 has strong tendencies to form double salts, and that sulphates have great affinities for one another.

We have seen that as charging proceeds the s.g. of the acid becomes denser and the E.M.F. rises. Let us now examine this question. Water is a very bad conductor, and dilute H_2SO_4 a good one; therefore, the weaker the acid, the worse the conducting qualities. If the dilute acid is strengthened by adding H_2SO_4 until it becomes very much concentrated, the conducting properties diminish; but this stage is never reached in accumulator work. Kohlrausch gives the following

table for the specific conductivities of an electrolyte made with water and sulphuric acid :—

s.g. at 18° C.	Conductivity at 18° C.	Per cent. in sol: H ₂ SO ₄
1'1036	5084	15
1'1414	6108	20
1'1807	6710	25

The arrowheads show direction of increasing conductivity.

It will be observed that, since the solution is put into the cells at s.g.s. varying from 1'130 to 1'170, the mixture is approximately a 20-per cent. solution, or one part concentrated H₂SO₄ to four parts water (in practice, one part to five) ; and again, since the s.g. at the end of a charge rises to 1'180 or 1'200, the solution is about one of 25 per cent., and its conductivity is about 10 per cent. better.

Great care is necessary in making up the acid solution. A large vessel must be employed, by preference, of lead with burnt seams. The acid should be poured into the water slowly, and cautiously, because the temperature of the liquid rises to a high point, and splashes might do serious injury, even producing blindness. The water must never be added to the acid. It is always safest to obtain the solution ready mixed.

A well-charged cell is found to have about half the resistance of a discharged one. This is due partly to the difference in the conductivity of the electrolyte, as explained, and partly to the surface of the plates being in a better conducting state when charged.

In the discharged plate the active surface is greatly diminished, owing to the presence of the large quantity of lead sulphate, which is a poor conductor, and con-

sequently troublesome to reduce. It might, therefore be inferred that an exhausted battery is more difficult to charge at the start than at later stages of the process ; and this, in practice, is the case.

By active surface is meant that surface upon which the current can do useful work.

Certain advantages exist from the fact that the resistance of the cells becomes less as charging proceeds. Were this not the case, with a dynamo giving constant E.M.F. for all currents within its capacity, it is evident that the charging current would rapidly diminish as the charge approaches the end, in consequence of the rise of the E.M.F. of the battery. It does diminish, but not in any great degree, if a shunt dynamo is used, although the counter E.M.F. (in this case, the battery pressure) may have risen as much as 20 to 25 per cent.

The necessity for keeping all the connecting strips short and of low resistance, the junctions clean, and the cables short and large, may be illustrated by an example. Suppose a set of fifty cells, with a normal charging current of thirty ampères, which has an E.M.F. of 110 volts. Since the fifty cells themselves give 100 volts, this acts as counter E.M.F., *i.e.*, in opposition to the charging current ; thus 10 volts is the true pressure which forces the thirty ampères through the accumulator, so that the total resistance for cells, cables, and connections is about one-third ohm. This is considerably increased if the connections are not clean, or the cells not placed close together to shorten the lead connecting strips as much as possible, and the cables large. It will also be observed that, if the charging current were raised to, say 112 volts a much

larger current would flow, since the forcing power would be twenty per cent. greater. It is evident also that the rise of E.M.F. in the cells, as charging advances, must materially reduce the effective margin of pressure, notwithstanding the lower resistance of the cell. The methods of regulating charging currents will be dealt with in a later volume.

The next point to consider is why boiling occurs. It must be clear that, as the surface of the positive plates becomes converted into lead peroxide, the material to be acted upon by the current grows less and less, and the plates become virtually smaller; consequently, the current becomes too large for the work demanded of it upon the plates, which results in the decomposition of the water of the electrolyte, and often warming it considerably.

However, in practice it would not pay to gradually reduce the current as the charge advances. Yet it can be experimentally shown that, by reducing the current in exact proportion to the diminishing active surface of the plate, boiling never occurs, and hundreds of ampère hours may actually be added beyond what is accomplished in the usual way. Theoretically, an infinite charge in point of time, but finite in quantity, might be given if the current is continually reduced to suit the lessening active surface of the positive, since the total quantity becomes the sum of a special form of an infinite series.

Boiling does no harm unless the paste is loose, when much material will be removed by the agitation of the liquid.

Frequent and prolonged over-charging, with currents about 30 per cent. below maximum, is the only way

to reduce badly sulphated plates, which are frequently found when the cells are allowed to run too low or to stand too long. When the positive plates are in a bad condition (generally due to the battery having been over-worked, *i.e.*, greatly exhausted, or owing to short circuits within the cell itself, which evidently produces a similar result, or to leakage), it is no easy matter to get them right again, since the conducting property of the paste has become very low. Under these circumstances, sulphates soon form and rapidly spread over the plates almost like a growth of mould. By patient and slow charging, this white sulphate, from want of adherence to the healthy oxide forming below, soon falls off in the shape of scale or powder to the bottom of the pot; and care should be taken that no portion sticks between the plates.

It must be borne in mind that the addition of caustic soda, or of the other materials mentioned, in a great measure prevents the formation of this white sulphate.

If, when the cells boil, the charging is stopped for half an hour or more, and is re-started, it will be found that boiling does not commence for some time; and this process may be repeated again and again. When boiling takes place a kind of gas battery is produced, both positive and negative plates being covered with a layer of gas. When charging is stopped, this gas escapes or becomes partly absorbed, so that the plates are once more exposed for a short time to the current, before the phenomenon recurs.

If too large a charging current is used for the area of the plates, buckling is likely to ensue, and very rapidly if the positives are in a bad state. Then, short-circuiting, due to plates touching one another in the liquid,

soon takes place together with a great loss of paste. Buckling is due to unequal expansion of the plates, and even under the best treatment this trouble arises if the makers have not given them a proper form. The paste expands on discharge, and *vice versa*; therefore it is absolutely necessary that such expansion and contraction should be symmetrical over the whole surface. These continual changes in the volume of the paste, after a time, loosen it from the grids; but, if these are uninjured, repasting can be resorted to. With judicious treatment, some years may elapse before this becomes necessary, and it is applicable chiefly to the positive plates.

It has been previously pointed out that the chemical action of the current on different parts of a plate is unequal, because the resistance between the places, where the current enters or leaves the plate, and the various portions of the plate is unequal. Indeed, practically, although this condition of things can be much improved, it is hardly likely that perfection can ever be attained in this respect. From these considerations it might appear that buckling must inevitably ensue, and the only reason why it does not is that, the charging and discharging current being kept low, there is no great tendency for the current to travel from plate to plate otherwise than over its whole surface. But clearly, if the current put in or taken out is too large, there would be a tendency to set up a more rapid chemical action on those portions of the plate nearest to the point or points where the current enters or leaves them. Hitherto the equalizing of the chemical action all over the plates has received the attention of manufacturers more with a view to obtaining a

CHARGING.

heavy discharge than from any other reason. It might be concluded from the foregoing remarks that, independently of many advantages which may accrue, by equalizing the chemical action over the plate surface durability to the battery would be given.

The difficulties which may arise with the negatives will be commented on later. Buckling may also spring from other causes to be considered in the next chapter.

It might be supposed from what has just been said that when boiling (due to the current at this time being too great for the active area of the plates) commences, the risk of buckling the positives may occur. However, this is not so, because the case is not the same as when the surface of the plates is actually smaller: there is still a large surface upon which the current can do its work, but, instead of forming PbO_2 , it decomposes the water of the electrolyte.

It is often necessary to give prolonged charges in order to remove any white sulphate that may form. In this event the current should be reduced, say to two-thirds or half the maximum; otherwise much paste may be removed. It must be well understood that overcharging improves the plates at all times, and *never* injures them, unless the paste be loose when the agitation of the liquid may remove a good deal of it, if the overcharging is continued for a long period.

From time to time, water must be added to the cells so as to keep the plates well covered. It has already been explained that, for the first few times, acid solution s.g. 1.130 or 1.150 should be employed to keep up the level; but if the s.g. or the electrolyte should fall below the normal, then the acid solution must again

be used until the normal is once more reached. It is, therefore, most desirable to place an acidometer in every cell, in order not only to indicate the s.g. of the liquid, but that, by its rise and fall, a fair estimate of the state of the plates (*i.e.* storage) may be arrived at. For instance, if the acidometer in a cell refuses to rise, then a careful examination must be made, as something is at fault; most probably two plates are touching, or one or more pieces of paste sticking between them. Again, if the apparatus rises slower, during charging, in one cell than in others, or if it should fall more in it than in any others at other times, then a leakage is taking place in that cell, probably due to one of the causes just mentioned.

When the accumulator has been in use for a long time and the plates have become very well formed, the s.g. of the electrolyte does not rise so much as it was accustomed to do in previous stages, and the nature of the boiling appears somewhat different. The gases then given off, although considerable, do not produce such a milky appearance of the liquid as formerly. The chief reason why the electrolyte does not gas so much is that the plates are better formed, and therefore a larger charging current would be required to make the liquid boil as white as when the battery was first erected. But, if this current were to be increased, the original effects would be reproduced, although that course is not advisable.

Positive plates do not assume their healthy colour till after several chargings, as the white sulphate sticks very obstinately to the plates when they have been allowed to dry; but before long, especially after a few discharges have been taken, it will be observed that the

white sulphate falls off as a white powder or in small scales.

It is of the greatest importance to keep the charging current within the permissible medium at starting, by some convenient method.

The plates in cells, no matter of what kind, should be so arranged that the resistance from every part of one plate to every corresponding part of the adjoining plate shall be equal, otherwise buckling will take place. The plates should also be so framed that they cannot shift.

An accumulator to remain in good health, like a human being, must be exercised gently and regularly; that is to say, the cells must be regularly charged and discharged with moderation. Some of the makers of lead plate batteries, also the Electrical Power Storage Company in their K type, give very high *maximum* rates of charging and discharging for their cells, in fact double those mentioned in this chapter. It must be distinctly remembered that such high rates are only allowable for short periods, and on exceptional occasions.

There is no better test for ascertaining the condition of the battery than by the colour of the plates. When the accumulator is first started, the negatives are a yellowish grey, and the positives dark brown, spotted with a whitish substance. If the first charge is carried on long enough, this whitish material, being the objectionable sulphate deposit, disappears, and from this time the colour becomes the test.

The positives should be dark red, chocolate, or plum colour; but when fully charged they look like wet slate nearly black. After a small discharge they regain their former appearance. If too much discharged, the white

deposit reappears in patches. Frequently a reddish scale appears instead of the white deposit. The best way to describe this colour is to say that it has a venetian red tint. The presence of this scale to a novice is difficult to distinguish, because, being red, it is apt to be mistaken for the proper colour of the plates; but on close examination, it will be found that it is really a coloured scale not firmly attached to the plate. A careful observer will never fail to distinguish this appearance after it has once been seen. The negatives soon assume a pale slate colour, which darkens slightly as the charging advances. They are, however, always much lighter than the positives. The upper edges of the positive plates generally appear grey, but this is of no consequence if limited to those parts.

It is possible to become a *connoisseur* in regard to the colour of the plates, for a constant observer can tell their true condition; not only whether they are of a good or bad colour, but also the exact amount of the charge they contain.

There is nothing special to add in respect to unpasted plates. All the instructions which have been given for charging a battery apply with equal force to these types, of which the Crompton-Howell cell takes the lead. A full description having been given of these, a recapitulation of their characteristics will here be unnecessary. It must be borne in mind that, although these batteries may be charged and discharged at higher rates than those just stated, it is by no means desirable to do so except on special occasions.

The red scale recently mentioned is more commonly to be found on the plain lead type of plate than on the other kind. It also frequently happens, in all types,

that the grid breaks at the edges ; but this is of no importance, unless the fissures extend very far towards the centre, in which case there is a danger of the grid breaking and creating a short circuit. These fissures are more common with the plain lead type than with the other ; but with the pasted ones they constantly appear when the battery has been in use for a long period.

Notwithstanding the losses necessarily incurred by the use of the accumulator, the latter is an economy in private installations, and not less so for public supply in some instances. There is no need to run the engine and dynamo during the many hours when only a few lamps are required ; also the plant may be smaller. Besides, the light is never cut off for a moment day or night, and a feeling of security exists from the knowledge that a breakdown need not be feared. Another advantage is that, during the cleaning of machinery or slight repairs, there is a sufficient reserve to insure light over the span when darkness would otherwise ensue, at great inconvenience to the household.

The following table of lighting hours has been drawn up by Mr. R. E. Compton, and is very convenient for reference.

LIGHTING HOURS THROUGHOUT A YEAR OF 8,764 HOURS.

DAILY LIGHTING.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Total per ann.
From Sundown to 11 p.m.	218	173	160	136	99	80	87	114	144	180	207	233	1821
From Sundown to 12 p.m.	249	201	191	156	130	110	118	145	174	211	237	254	2186
From 6 a.m. to Sunrise	63	36	7	...	...	...	...	...	...	12	45	63	254

It will be noticed that the hours from six a.m. till sunrise and from sunset till eleven p.m. for the whole year are 2,075, or say, in round figures, 2,000. These figures are a guide to the number of hours during which one or more lamps are required.

In London it would be fair to consider that in 120 days out of the year (in consequence of the fogs and darkness overhead) light is required between sunrise and sunset, so that artificial light would probably be needed for 2,600 hours per annum, and in some years as much as 3,000 hours.

Although the last table states the number of lighting hours at various periods of the year, no idea can be formed as to the time in the morning after which artificial light can be dispensed with and the hour in the afternoon when lamps become necessary.

The following table contains information on this point to a degree of accuracy sufficient for practical purposes in London and its neighbourhood, since the hours given are based upon the time at which the sun rises and sets at Greenwich, and a correction must be made in regard to places where this hypothesis does not hold good.

TABLE

Showing to what hour in the morning lamps are required for each month of the year.

	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.
Beginning of the Month.....	8.0	7.30	6.30	...	...	...	...	...	...	6.10	7.0	7.45
Middle	...	7.20	...	...	...	...	...	...	...	6.30	7.20	8.0
End	...	7.0	...	...	...	...	...	...	...	7.0	7.45	8.10

TABLE

Showing the time when lamps are required in the afternoon for each month of the year.

	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.
Beginning of Month	4.0	5.0	6.0	6.30	7.30	8.0	8.15	7.45	6.45	5.30	4.20	4.0
End	4.30	5.30	6.30	7.15	8.0	8.20	8.0	7.0	5.45	4.30	4.0	..

The hours given in these tables are only approximate, being averaged over the portion of the month to which they refer.

CHAPTER IV.

DISCHARGING.

FOR pasted plates the discharge should not exceed four ampères per positive plate, in a cell of E.P.S. L type. This is at the approximate rate of 8 ampères per square foot of positive plate. Returning to our old examples: For a 15-plate E.C.C. cell, 28 ampères should be the maximum current for discharge; in a 23-plate cell, 44 ampères; and in a 31-plate cell, 60 ampères. The charging and discharging currents may, therefore, be equal for the maximum in all the recent makes of plates. Moreover, it is found that the larger the discharge the lower the internal resistance of the cells at the time; so the accumulator, to a great extent, becomes its own governor. This is a remarkable property, and may be comprehended in this way: there is practically no fall of E.M.F. for any discharge within the limits allowed, because the internal resistance of the cells diminishes as the current increases. But for this property, batteries could not be employed for practical purposes, because their efficiency would be too low, and a regular pressure could not be obtained without much trouble and risk of failure.

The current starts at one point in the circuit, and returns to the same point ; but, in its course, it gradually loses pressure, *i.e.*, E.M.F. Consequently, the pressure of the current differs at every part of the circuit ; and at those parts, where the work demanded of the current is heaviest, the fall of pressure will be greatest.

Since the E.M.F. of one cell is two volts, of two cells four volts, and so on, it is evident the total E.M.F. is obtained only between the ends of the battery. When testing one or two cells, low E.M.F. measuring instruments, or, as they are generally called, low-reading voltmeters, are employed. But such instruments would be destroyed, if used to measure a high E.M.F. ; and one made to measure high E.M.F. would be unsuitable for low pressure, except in combination instruments, which are really equivalent to two separate voltmeters. It is with a low E.M.F. voltmeter that the state of each cell is examined.

If in any cell the pressure is below 1.9 volts, then it requires charging, for the residual charge has been reached ; and, if the other cells are charged, it must be cut out of the circuit during discharge and replaced when charging is renewed. Only, the connections are altered for the time being, the cell not being moved.

There must always remain about 25 per cent. of the total charge the cell is capable of taking ; otherwise troubles arise, so that the moment the E.M.F. of the battery falls below an average of two volts per cell, which indicates that this limit has been reached, charging must be resorted to.

When the plates are nearly discharged, that is, far below the minimum permitted, nearly all the paste on the positives is in the form PbSO_4 . This soon decom-

poses into the higher sulphates which ruin the plates, and, apart from other consequences, cause them to buckle when charging is proceeding. It is, therefore, evidently imperative to keep a residual charge sufficient to give an E.M.F. of two volts per cell. In fact, after being fully charged, the cells may be steadily emptied to the permitted limit, giving practically two volts per cell the whole time. Then comes a rapid fall of pressure, soon reaching zero point. There is a great diversity of opinion as to the cause of a sudden fall in the pressure when a certain state of discharge has been reached. Some authorities think that the negative plates become slightly reversed when this phenomenon takes place: others say there is not the slightest foundation for the supposition. The most reasonable and probable cause for the sudden drop of pressure is that given by Mr. Robertson, and referred to in the previous chapter.

Too quick a discharge buckles the plates, and a very sudden large discharge drives the paste out of them, although the current may be well within the maximum. Therefore, when motors are started, it should be done through a variable resistance, apart from the requirements of the motors themselves. For the same reason, large batches of lamps should not be simultaneously turned on. Quantities of gas, driven from the plates at the moment of sudden heavy discharges cause the injury. A large sudden discharge may be regarded roughly as one of 50 per cent. of the maximum. With the K type of plate, and with plain lead plates, the risk of damage is far less.

Should a cell in the battery be dead (*i.e.*, give no E.M.F.,) from overwork, then, if not attended to at once, and cut out of the circuit during discharge, the outgoing

current will pass through it and start charging the cell in the reverse direction ; thus converting the positive plates into negatives, and *vice versa*. This will naturally destroy the cell, because, when charging is commenced, the opposite action takes place ; and, eventually, the plates sulphate, buckle, and lose their paste. A dead (*i.e.* worked out) cell will also produce a counter E.M.F. of two volts. The total loss of pressure will, therefore, be that of the cell itself plus the counter E.M.F. ; in other words, a cell, giving no E.M.F., lowers the pressure on the circuit equivalent to the removal of two good cells. But, if it be dead by reason of the plates touching or from any other cause, the loss of E.M.F. will only be that of the cell itself, as it sets up no counter E.M.F. in this case.

When a battery is left standing, many have found that large quantities of hydrogen gas are given off ; whilst others have not found this to be the case in any great degree. If a large quantity of this gas be removed from the negatives, it seems highly probable that the latter are giving off a portion of their effective quality ; and as a natural result the positive plates cannot be so much discharged : consequently, there must be a loss of storage, because the positives cannot be discharged so completely. It would, therefore, appear that, if a battery is left standing for any considerable time, a great loss of storage must ensue, though insulation may be good. This, however, is contrary to the author's experience. He has found that hydrogen is given off from the negatives, but the amount of the gas so lost depends a great deal upon the condition of the plates, and that when they are in good order and well charged after standing for a month, the loss of capacity is very

small. In fact, on starting charging, a very few minutes elapse before boiling sets in ; which is a ready test for ascertaining whether there has been much leakage. The writer has also found that the escape of hydrogen from the negatives is almost insensible a few hours after the charging has been completed. Mr. Crompton expressed an opinion that the action of light had some effect upon a cell, but Professor Ayrton conducted a series of careful experiments which proved the contrary. Consequently, if light has any action whatever in this instance, it must be insignificant.

With the Crompton-Howell cell the electrolyte is very frequently found to discolour, generally assuming a slightly purple hue. In all cases discoloration of the electrolyte is due to foreign substances, which were present before the liquid was poured into the cell or derived from some soluble foreign salts existing in the plates themselves. These foreign salts are more frequently found in plates of the unpasted type. The lead employed in the Crompton-Howell plate contains traces of gold, and to its presence is attributable the purplish discoloration. As already mentioned, in most cases permanganate of potash is the cause.

In order to give a general idea of the storage capacity of cells in practice, a 15-plate E.P.S. cell may be taken as an example. This is found to be 330 ampère-hours available, and, since the maximum discharge is 30 ampères, it is obvious that such a discharge can last for eleven hours, and still leave the required residual charge. If the discharge is at a lower rate, then, of course, the time occupied in emptying the cells will be proportionately longer.

A rough rule for capacity is the following :—one

hundred ampère-hours per *square foot* of positive plate (not surface). This is equivalent to fifty ampère-hours per *positive plate*, in a section of the size most generally in use. Also the capacity may be approximately taken at twenty-two ampère-hours *per plate* in a section.

It is usual with accumulators to measure their capacity in "ampère-hours." An ampère-hour means one ampère flowing for one hour.

All the foregoing remarks may be taken to apply equally to the unpasted type, which, however, has the advantage of being able to withstand a heavier discharge without injury to the plates. The limit of possible discharge is shown when the pressure of the current begins to fall appreciably. These heavy discharges are not to be recommended as a general rule.

The author particularly recommends purchasers of a secondary battery to discount manufacturers' working figures. It is well to deduct from the charging and discharging at rates at least 10 per cent. of the figures they quote; also to regard the available capacity at 25 per cent. less than that given. There is no doubt that the figures in the makers' price lists are possible, but naturally they state as good a result as can be obtained, and they do not guarantee that these values can be maintained year after year without fail. The writer's experience is that, if the allowances just mentioned are made when a battery is purchased, and are adhered to in practice (though the capital invested to do a certain work may be somewhat larger at the start), the final result is most favourable to the purchaser. Money, vexation, and inconvenience will be saved in a great degree.

CHAPTER V.

FAILURES, THEIR CAUSES AND REMEDIES.

THIS chapter is probably the most interesting to the majority of those who possess installations, because the batteries are generally put up by the makers. The theory has not an interest for everyone, but when difficulties arise in daily working inquiry is at once called for.

For the most part the remarks which follow may be taken to apply to the unpasted, as well as to the pasted, type of plate, except where it is evident from the context that one of the types alone is referred to. To deal completely with the pasted and the unpasted types separately would need so much recapitulation as to become confusing.

It cannot be too strongly impressed that, whether the plates are pasted or whether they are not, the chemistry and phenomena are the same, so that the rules to be observed for charging and discharging, as well as the troubles which may arise, are the same for both. One distinction alone exists: in the pasted type there is paste which may become loose, scale, or fall out; whereas in *the plain lead type* scale only may separate.

There are two troubles which beset most accumulators, viz., buckling of plates and bad forms of sulphating. To these all other difficulties, with few exceptions, may be traced. Buckling is almost unknown in well-managed installations.

When cells are left to rest for a long period, they ought to be thoroughly charged; and once a month afterwards a good charge should be given them. This will prevent the plates from getting into bad condition in the event of total discharge by leakage and local action, which are always present in a small degree, even under the most favourable conditions.

If by any chance the positive plate should sulphate deleteriously, the action must at once be stopped or the battery will be spoilt. Bad sulphating is shown by the chocolate colour turning greyish all over the surface, or in patches, or the venetian red colour appearing, as mentioned in the preceding chapter.

The colour of the edges of the plates gives an indication of what is taking place over their surface; so that, if there is not a marked difference in colour between the positive and negative plates, a careful examination should be made. The results of bad sulphating are scaling, the falling out of paste, buckling, and short-circuiting, and, in the last case, the grids generally become rotten; whilst the causes may always be traced to the acid solution being too weak or too strong, but more generally to the cells having been habitually over-discharged, or left standing for a long period with little charge in them. Also short-circuiting will naturally do this, since the plates become discharged. A leakage in the circuit may discharge the battery without the knowledge of

the user. Bad insulation of the cells themselves will produce the same result.

An easy test for the insulation of the accumulator is to wet the back of the hand with weak acid and place it against the shelves; should the insulation be faulty, a pricking sensation is felt, which becomes painful if 100 volts are used. Should higher voltage be employed, it is not safe to make this experiment. At 200 volts the shock is strong, but it varies with every individual; for whilst some people do not object to 210 volts, others cannot stand sixty, especially those who suffer from damp hands.

All currents may be regarded as more or less dangerous to the person after 250 volts, but the pressures of 60 to 100 volts, which are harmless under ordinary circumstances, may prove dangerous under peculiar conditions. For instance, a man may be on a pair of steps placing a new lamp in a fitting, and unexpectedly get a slight shock, due to leakage or otherwise, and then the start it gives him may cause a fall from the steps. It is always advisable to cut both leads when anyone is attending to fittings or doing any work on the circuit.

To return to the cure for bad sulphating, a continual charging below maximum rate, half to start with, for a prolonged period, will gradually reduce the unhealthy sulphate to the healthy form, and finally charge the plates by conversion of the PbSO_4 to PbO_2 . The task is tedious, but it must not be hurried, or the positives are certain to buckle. Most of the white sulphate will fall off in scales, but should any stick between the plates it must be pushed down with a piece of wood or a flat strip of ebonite, the latter being the best. But on no account should a piece of metal or any other conduct-

ing substance be employed for this purpose. When white sulphate exists upon the positive plates, it shows that most of the oxide has been converted into PbSO_4 . Both these sulphates are very bad conductors. Consequently, when the white sulphate is observed, it may be concluded that a great resistance is offered to the current doing its work, and is in a manner equivalent to the plates having a much smaller active area. The maximum charging current is, therefore, too large; but the current may be increased as the white substance falls off or disappears. If the sulphating has become very bad, these scales often separate from the plate carrying with them the blocks of paste which they overlie. This is very vexatious, for the capacity of the battery becomes much reduced by loss of active material, and great trouble is experienced in getting from between the plates these pieces, which, if not removed, short-circuit the cell.

In the most recently improved cells, in which the plates are situated farther apart, any paste falling out will occasionally hang up between the plates, although it would appear at first sight to be impossible; so that absolute reliance must not be placed upon the statement of the makers that paste *cannot possibly* stick between the plates. It may occur in four ways. The first is, when the plates are in bad order they frequently lose their flatness, and, consequently, the original distance between them is no longer maintained. The second is that some samples of paste are apt to throw out short crystal needles, which arrest the fall of the paste. The formation of needles in pasted plates is sometimes due to the character of the paste itself. Extremely slow charging is apt to produce needles with all plates, when it is continued over a long period. This kind of charging

may be described as ten per cent. of the permitted maximum. Thirdly, the opposite blocks of paste may so fall as to encounter one another. Finally, pieces of scale may separate and be of such a size that they cannot fall clear between the plates.

When a battery is first erected, it frequently happens that very large scales come off the positives. The plates in new cells must, therefore, be watched for a few weeks, and any scales that may be observed between the plates should be removed. If this is done carefully, the trouble soon disappears.

When the plates are in a very bad condition, a good plan is to clear a little of the white deposit off each positive with a stick, and so offer some healthy surface to the current, lowering the resistance of the battery and facilitating the reducing process.

After bad sulphating the capacity of the cells must always be less, in consequence of the loss of some of the active material. Where the fault is great, the best plan is to clean the battery properly.

The cleaning of a battery consists in removing the sections from the cells (after a good charging), separating the sets of plates, and scraping the white deposit off the positives. There is no need to remove the plates from the lead strips, for by bending them apart plenty of room is allowed for manipulation. In cases where the plates cannot be parted, they must be reached as well as circumstances permit; and generally no difficulty occurs. The wire-brush material sold under the name of "carding" will serve to do the work satisfactorily. A piece of this is cut to six by four inches, and nailed to a block of wood half an inch thick, and having a handle, if found necessary, for reaching between the plates. The

brush is now applied to the positives till they appear their proper colour, and they are finally washed with the electrolyte, and on no account with water, or sulphating will set in immediately. This done, the cells are again made up, when the old solution may be used again, although it will generally be found more convenient to put in fresh electrolyte.

The cells are then ready for immediate charging, and they should be regularly overcharged and watched for some time. The cells also should be cleaned from any deposit. The old acid answers well for washing the plates with, and for placing the negatives in whilst waiting; for these, being wet, are injured by exposure to the air. Should this solution be employed a second time, it must be allowed to stand until it becomes clear before further use. (If the old acid is rejected, it may finally be used to destroy weeds on roads and paths, so that nothing need be wasted.)

There is considerable risk of accident from short-circuiting, if a cell is moved with the electrolyte in it. Therefore, unless skilled labour be employed, it is best to syphon off the liquid with a $\frac{3}{8}$ -inch red india-rubber tube, filled with solution by dipping it bodily into a vessel of liquid and then keeping the thumbs over the ends to prevent escape, whilst it is applied to the cell. Under no circumstances should the tube be sucked in order to "draw the syphon," as this proceeding is highly dangerous, because of the poisonous and corrosive character of the acid and the liability to receive a shock in the mouth. So long as the electrolyte touches the plates there is possibility of short-circuit. This must, therefore, be drawn off completely, and then no accident can possibly arise. There is a perpetual

syphon (manufactured in France) which is always ready for use, without being "drawn," but, as now made, it is too large and clumsy to be convenient.

If the positives are past recovery, it is the cheapest to have a new set, which can be obtained from the makers at a very moderate cost in exchange for the old plates.

The process just described for cleaning a battery is employed for buckled plates, with the difference that these require to be straightened. This is effected by placing between every positive plate (or negative, if at fault) boards of such a thickness that all the plates are parallel and in the same position as when in the cell, or the connecting strip of lead will be bent or broken. The plates, with the interleaved boards, are then laid on their side upon the ground, and pressed till they are quite flat. A portable lever-press or a screw-press is generally used for this purpose. No attempt should be made to flatten by means of hammering, as this is sure to loosen the paste. As soon as the battery is reconstructed, charging should be commenced.

When the negatives are removed from the cells, they, on drying, become hot; and this is probably due to the finely-divided lead they contain oxidising in air. Negatives exposed to the atmosphere for a length of time especially if it be moist, show signs of blistering when in use. This is very troublesome, for the blisters frequently become detached in the form of scale, which sticks between the plates, thus partially short-circuiting them, and eventually causing the positives to sulphate.

Blistered negatives often exist which do not drop the scale, and, in this event, no evil consequences follow; but the risk should not be incurred. With new cells the negatives often blister from careless manufacture. If

a cell becomes completely exhausted, or, by chance reversed, the negatives buckle ; but, as a general rule, it is only the positive plates which are subject to this trouble.

It is always advisable to charge well before cleaning or straightening plates, because the air does not then act so prejudicially upon them.

If the positives sulphate badly, the surface becomes very hard ; but when they are in good order the surface of the paste, as well as that of the grid, is soft, and the colour comes off readily on the finger like pigment.

When the positives get into a very bad state, the negatives are generally in a similar condition.

Much loose scale, from positive or negative plates, may be removed by taking the sections apart and agitating the sets of plates, separately, in a cell or tank of the electrolyte.

Buckling, apart from the causes indicated in the preceding chapter, may be produced by too high a charging or discharging rate. It also often arises from pieces of loose paste sticking between the plates, which cause an unequal resistance between the surfaces, so that expansion and contraction are not symmetrical. When this occurs, the plates are often of a good colour. In all cases the framework, or other means employed to keep the sections together, must be so made as to allow for the expansion of the positives. The allowance need be very small, since the plates are generally put together in the expanded condition—*i.e.*, in the unformed state ; but slight after-variations should be taken into account. Sometimes plugs of paste drop out when everything appears right, and the cause is usually found to be that a large discharge has been taken suddenly. Consequently, this proceeding should be avoided.

If a film appears all over the inside of the cell, partially obscuring the plates, the water mixed with the acid has been impure. When this occurs, much inconvenience arises from inability to see the edges of the plates properly; but no actual harm is done, and it can be entirely avoided by allowing the solution to settle after mixing, and baling it out, leaving the sediment undisturbed. A slight quantity of powder at the bottom of the pots will always be found; this consists chiefly of the white sulphate removed during the first few chargings.

With ordinary care the author has found that, after working cells for three years, the loss of paste is so small as hardly to be worth mentioning. Some experimenters have for the same period found a considerable weight of deposit at the bottom of the cells. It may be concluded either that the batteries were not properly managed, or the sections were left standing in the air for a considerable time before putting them to work, or that the plates were faulty in their manufacture.

The plates must never touch the bottom of the cells. Therefore, care should be taken occasionally to observe the condition of the bottom block or frame.

The construction of the sections now generally employed is such that both sets of plates cannot be short-circuited by deposit in the cell. If the wooden support should give way from any cause, there is the chance of the glass being broken.

A temporary cure for plates buckling is the insertion of glass strips or wooden wedges, to prevent adjoining plates from touching; but the cause must be removed at the first opportunity and the plates straightened.

It sometimes happens that the dynamo leads have been wrongly connected, in which event the plates

throughout the battery become reversed ; the negatives change to chocolate in colour, and the positives to slate. Such a mistake ought to be carefully guarded against. Should it occur, there is only one remedy, namely, to discharge the battery completely, through a resistance frame or through the lamps, so that the maximum discharge allowable is never exceeded. This resistance may be reduced as the E.M.F. of the battery becomes less. When the accumulator gives no E.M.F., or a very low one, the dynamo wires must be correctly joined up, and charging should be started very slowly at first and with a resistance, for a time, in one of the dynamo leads to keep the current small ; since there is little or no counter E.M.F. to overcome till the cells charge up in right way. Running the dynamo slowly will answer the same purpose as the insertion of a resistance, but the latter is more convenient. It will take a long time to get the plates into good order again, and perhaps many troubles will ensue, each of which must be treated in the proper way ; but matters soon mend, provided the mistake be discovered early.

A resistance frame called, for brevity, "a resistance," consists of a frame of wood with a number of coils, either of iron, german silver, or platinoid wire, stretched across it. The whole contrivance appears like a frame, containing a large number of spiral springs placed close together. The frame is sometimes made of metal, in which case the coils are insulated from it by means of slate, or porcelain, supports. Arrangements exist for permitting the current to flow through one or more of these coils, so that the opposition to the current may be varied at will. The wire is proportioned in its section so as to carry the desired current.

A resistance frame of modern type is shown in Fig. 33.

Platinoid wire possesses so many advantages over ordinary metals that its properties ought not to pass unnoticed. For the same length and size of wire the resistance of platinoid wire is almost double that of german silver. Platinoid does not oxidise appreciably in air, and its resistance for various temperatures is



Fig. 33.—Resistance Frame and Switch.

fairly equal ; it is also exceedingly hard. The wire is also very strong, and its cost is but a very little more than that of german silver. Therefore, for any definite resistance, far less platinoid wire is required than if german silver were used. The word platinoid would seem to imply that platinum is present in its constitution, but this is not the case. There is a small amount of

tungsten in the alloy. Its melting temperature is high, which renders it very suitable for use in resistance frames. The chief trouble encountered with such frames is that, in course of time, the metal is apt to become crystalline and breaks. This may be due to three causes, or to any, or to all of them combined: (1) The passage of the current; (2) the high temperature to which the wire is subjected; (3) the natural process of oxidation. German silver is especially liable to this defect. Where room would admit of it, by far the best material for use in artificial resistance is galvanised iron-wire. But to produce an equal resistance in replacing platinoid, about twelve times the length of wire of the same gauge is necessary. Liquids are sometimes used as resistances.

If a cell gives no E.M.F. from any cause, except complete short-circuit, then the discharging current has the effect of charging such a cell the reverse way, and the plates become reversed. The proper course to pursue is always to disconnect such cells, when discharging, by bridging them over with a wire and to reconnect when charging. In time the cell will become charged equally with the rest, and it can then be permanently replaced. To cut both connections of such a cell is unnecessary; to break the circuit at one end is sufficient.

Proceed in this way: Disconnect the positive strip of the dead cell from the negative of the next, and clamp one end of a wire to the negative strip of the dead cell (equivalent to positive of the adjoining one) and attach the other end of the wire to the negative strip of the next cell, which has just been disconnected.

When the charging commences, be careful to remove this wire before connecting up, otherwise the cell will be

short-circuited through it, damaging the plates and perhaps causing an accident by fusion of the wire, if the latter is too small. The whole operation may be facilitated by the use of a two-way switch, with a break between the contacts, suitably connected, by which means the cell can be put in and out of the circuit at pleasure.

All conductors in the accumulator house should be so placed that, if the insulation wears off by the action of the acid and of the fumes, short circuits will be impossible. The leads may be carried on porcelain insulators, and every wire should be kept well apart.

It is very desirable that all the leads should be painted with Griffiths' anti-sulphuric acid enamel, as it will be found a great preservative.

Never add concentrated acid to the cells, as the grids will soon become rotten if this is done. Never test a cell for E.M.F. by "flashing," which means taking a short wire, placing one end firmly on the positive strip of a cell and rapidly touching the negative strip (or *vice versa*), in this way producing a flash if the cell has life. It is the old method of testing, which, if frequently resorted to, soon spoils the plates, and no scientific result is obtained. The proper way to test is with a lamp or voltmeter, as before described, combined with the acidometer.

When the plates are badly sulphated, the internal resistance of the cells is greater, and consequently the E.M.F. for daily use is much lower. Their capacity, also, is less. Charging continued till boiling occurs, without further observation, may result in erroneous conclusions, for clearly the less the capacity of the plates *the sooner* will the phenomenon occur, and everything

is supposed to be in good order ; whereas a serious fault may really exist, for the plates may be in bad condition, or much paste lost, or many cells dead. The boiling in the latter case arises from the charging current being too great, since much counter E.M.F. has been removed. Again, it may happen that no amount of charging causes the cells to boil, indicating that nearly all the paste has fallen from the plates. Even in this condition the cells act as regulators to steady the light, but they have scarcely any capacity.

An accumulator only regulates to a very small degree, say, for variations of pressure not exceeding 2% when the current flowing into the mains equals half the maximum discharging current of the battery, and $\frac{1}{2}$ % only for a current to the lines equal to maximum discharge. For large variations of current pressure, although the battery improves matters, the regulation is very imperfect, and can be seen at the lamps.

If at any time the plates of a fully-charged cell are taken out of the electrolyte, then, on making up the cell again, the s.g. of the liquid put in should be the same as it was before the removal. If acid of a lower s.g. is used, no amount of charging will appreciably raise its density, because the PbSO_4 has already been reduced to PbO_2 on the positives as far as was possible. Consequently but a very slight further chemical action can take place in the electrolyte.

At all times when a cell is charged as much as possible, whether the plates are in good or bad order, a point is arrived at when the acidometer indicates no further change in the s.g.

Grids are made of lead or alloy of lead and antimony, the proportion of the latter being 10 per cent. This

alloy is much harder than lead, and apart from ordinary advantages there is one which claims particular attention, and that is the possibility of repasting the plates when required. The first expense of a battery is so large, and the renewal of the whole of the plates in the cells so expensive, that it pays the owner to repaste his plates whenever necessary. With proper attention and fair usage, years may elapse before this is required; but the manner of proceeding is described for the benefit of those who may wish to act upon the suggestion. The value of the process may be estimated when it is stated that the author had a battery of fifty-four cells which lost most of the paste, and its capacity became very small. The whole accumulator was repasted by unskilled labour for an expenditure of about ten pounds, the result being that the battery was as good as new. Sometimes only a cell, here and there, wants renovating instead of the whole set.

Proceed as follows:—Take the sections to pieces and spread the plates a little when the construction admits of this being done. Start with the positives, and mix up a stiff paste of red lead and H_2SO_4 , one part commercial acid to two parts water. The paste eventually assumes a dark reddish-brown colour, and more acid must be added until all appearance of red lead is gone. The paste then is chiefly composed of PbSO_4 . It is possible to buy PbSO_4 pure, and it is well to do so since it is less impure than a mixture of red lead, which generally contains much carbonate. The spreading of the plates allows the hand to reach every part of each grid. The paste is best laid on with a small wooden board, and the surplus scraped off with a piece of iron-hooping. The plates are now bent back to their normal

position, and set aside to dry. The paste should then be perfectly hard and adhering; if not, its consistency is at fault. A few trials will determine the point; a twenty-four hours' drying in a moderate temperature is sufficient. The plates are now ready. The negatives are treated in the same way, only the paste is made with litharge. The sections are now made up, placed in the cells, and all is made ready for charging. Probably thirty hours or more will be required to form the plates, after which every hour of charging is storage, when the chocolate or plum colour of the positives and the familiar appearance of the negatives are soon attained. Sometimes the forming is far more rapid.

Repasted cells must be cut out during discharge until they boil, and in no case should a repasted battery be discharged till all cells boil.

It is possible to paste the positives with PbO_2 purchased under the name of puce-coloured lead, in which case ready-formed charged plates are made at the start. It is found by many persons that the PbO_2 paste fails and soon falls out; but this has not been the experience of the author. There is a physical difference between pasting with PbSO_4 and PbO_2 . In the first case the substance is laid on in the expanded form, and in the latter in the contracted state. If the manipulator can succeed with PbO_2 , there is great saving, since the cell is ready for a small discharge at once. Repasting can be accomplished with economy only when the grids are not rotten. Some experimenters obtain better results by pasting both positives and negatives with red-lead paste; others paste both sets of plates with litharge.

Vulcanized and pure india-rubber, if of good quality, does not deteriorate in the acid, but, if bad, it falls to

pieces in a short time ; indeed, even a few hours may break it up. Very commonly vulcanized india-rubber is adulterated with lead, on which account its good non-conducting properties are greatly impaired, in consequence it has frequently been found to fail as a good separator.

It may be of importance to some persons to know the best means to adopt when it is desired to transport a battery to a distant place, after having been in use, so that the plates may not be injured. The sections should be taken apart and the plates pressed together, either wet or dry, so that only one face of each of the end ones is exposed to the air. Each batch can then be wrapped in oiled brown paper. When it is not possible to follow this course, the sections should be kept from contact with the air as far as possible by enveloping them in oiled paper, and the intervals between the plates should be stuffed with hay packed in oiled paper. When the battery is put up again, it is treated in the same way as if it were a new one. If this method of transporting be adopted, no harm will be done to the plates ; but it will be advisable to set the cells up again as soon as possible.

There is little to be said regarding unpasted batteries, for, beyond clearing any bad scales which may cause short-circuits and occasionally straightening buckled plates, there is nothing to be done.

Spongy-lead plates are generally treated with nitric acid, and the frequent non-success of this type has been attributed by many to the fact that the acid has not been entirely washed out before the plates are brought into use. Some persons even go so far as to believe that spongy-lead plates cannot possibly be freed completely *of the acid*.

Spongy-lead plates may scale, blister, and break away in the same manner as the pasted ones; and the causes are identical. All these bad results may, with proper management, be avoided. One of the best insulators appearing in recent times is celluloid, which is cheap and quite as good as ebonite. Messrs. Crompton-Howell use this material in their cells.

The recent **K** type of plate is made by the E.P.S. Company, which may be regarded as a compromise between the pasted and the plain lead type, since the grid is a solid plate; and it must be remembered that in all cases the grid itself plays an active part as well as the paste. The failings, no less than the virtues, of both types of plates will be found to exist in the **K** type. The virtues, which have the balance of advantage, may be summed up as follows:—The grid is stronger and consequently more easy to straighten if needed, as well as to paste, should this be required; and the paste itself, not being in blocks, does not fall out so readily.

So much has been said in this chapter on failures that it might be supposed an accumulator was simply a source of annoyance. This is the case only where the accumulator is not watched and any little fault at once remedied. As a rule very little trouble is given, and none at all if competent persons occasionally view the installation. In order to bring all the facts concisely before the reader, the final chapter is in the form of a summary.

CHAPTER VI.

TESTING A SECTION.

IT is nouncommon occurrence for an expert to be called upon to test a cell for its charging and discharging current, its capacity per pound of lead, and wearing qualities, also as to the best specific gravity to be given to the electrolyte. A few words on this subject may prove useful. To speak the actual truth, there is no method at present known for testing a cell satisfactorily in a short space of time. The author has frequently been called upon to make such tests, and the task has always been undertaken with great hesitation, seeing how often the best known experts have erred in making these rapid investigations. An attempt will be made to show the best way of finding the results sought for, when time is no consideration. In doing this, it is best to take several cases; and in all instances let it be assumed that the sections are built up of plates made of lead of a pasted, or unpasted, or crossed type. In giving the instructions it must be understood that minute details are omitted, for amateurs will not be called upon to do this class of *work*.

CASE I.—The cell to be tested has its data given by the makers, they having already experimented largely to discover what suits their plates the best; and the object in view, therefore, will be to verify their statements. It may, in such a case, be presumed that the density of the electrolyte as given will be fairly correct and need not be further questioned. It may be assumed also that the maximum charging and discharging currents stated will likewise be correct, at any rate for short periods. The points, consequently, which remain to be ascertained are the best charging and discharging currents for practical purposes. These latter being known, there is no difficulty in making the deduction of the capacity per pound of lead. The more the plates are charged and discharged without undue strain, the larger will be the capacity until a working maximum is reached. Consequently, the capacity will vary in accordance with the previous usage to which the section has been subjected; and also for rapid discharges the capacity is always less than for slower discharges.

Proceed to test, for the charging and discharging currents, thus : For a period of, say, one week, charge and discharge daily at the rates given by the makers ; charging until the cell boils, and discharging equivalent to one-half of the given capacity. If at the end of this period all is right, continue in the same way for another seven days, but discharging equivalent to two-thirds of the capacity given by the manufacturers. For another seven days continue in the same way, but discharge to three-quarters of the stated total capacity. If at the end of this period—viz. three weeks—the plates appear in perfect order, it may be assumed that the section has fulfilled what has been promised for it for a short duration,

It will be now well, for a period of three months, to charge and discharge at the rate of 10 per cent. less than the given maximum, and to discharge about three-fourths of the given capacity. This need not be done daily, but say twice or three times a week over the three months. If, after this period, nothing shows itself to be wrong, the cell may probably be used for many years with the method employed over these three months, for it is never desirable to work to the limits. The next step is to ascertain the capacity with heavier discharges. It will only be necessary to discharge at increasing rates of, say, 10 per cent. at a time, observing the interval which passes between the beginning of the discharge and when the E.M.F. drops to a considerable extent. This will show the capacity in every case for given discharging currents, assuming always that the section has passed through the three weeks' treatment first mentioned. These discharging rates may be increased enormously, but it will be found that the E.M.F. will fall considerably. It will, therefore, be necessary to make these observations with a voltmeter, and to consider that the maximum discharge has been reached when the voltmeter reads 1.9 volts. When any fixed discharge has been decided upon, the experiment should be repeated again and again for, say, a dozen or two dozen times, to observe the effect on the plates; and then, if nothing is found amiss, the section will bear this treatment.

To ascertain the heaviest charging current that may be used, it will only be necessary to increase this current until the liquid begins to effervesce considerably, for at this point it is indicated that the surface of the plate is insufficient for a current to work upon, and is therefore doing part of its duty in decomposing the electrolyte.

When the maximum charging current has been settled, it should be employed for at least two or three dozen times in order to observe the effect it may have upon the plates, the plates always being discharged to at least one-half of the estimated capacity before starting their charging.

It must always be borne in mind, when cells are employed for heavy charging and discharging, it is rare that they last as long as when used more gently. When they are employed with the milder treatment, six, or even twelve months is not too long for ascertaining their probable durability to extend over years.

CASE II.—No data given. Here the density of the electrolyte has to be ascertained. It is well known that with lead plates of any kind the acid solution should never have a s.g. less than 1.130, and never exceed 1.220. It is practically settled by experience that the electrolyte should not be lower than 1.150 in the discharged cell, nor higher than 1.210 in a charged cell. Therefore, it will be safe to use an electrolyte, to start with, of 1.150. When the plates have been charged and discharged many times, say, thirty, and the electrolyte does not become denser, when the plates are charged, than, say, 1.200, it indicates that probably it would have been better if the first acid had been 1.160, instead of 1.150; for in this case the liquid, when the plates are charged, would rise to about 1.210. The reason why it is desirable to get the electrolyte up to 1.210, when charged, is that the stronger the electrolyte the greater the E.M.F. (up to a certain point); but if the density considerably exceeds 1.220 the probability is that the lead plates will be attacked by the solution.

To ascertain the charging and discharging currents

the plates themselves must be examined to see if their construction is good (in accordance with remarks made in previous chapters), and if they are very porous; in which case both these currents may be taken as equal. Otherwise the charging current will probably be found 20 or 30 per cent. less than the discharging current. Assuming that the plates to be tested are not positively faulty, a charging rate may be fixed from the figures stated in an earlier chapter, calculated by superficial area. All the remaining tests may be made in the same way as mentioned in Case No. 1. If the plates are faulty, they will show it at a very early stage, probably after ten or twelve chargings and dischargings.

GENERAL.—There are some other points to be taken into consideration besides those which have been discussed. Speaking generally, they are the following :—

1. Whether the plates are of good shape.
 2. The sections properly built.
 3. That any deposit at the bottom of the cell shall not short-circuit the plates.
 4. That the plates may be easily taken apart.
 5. That they may be packed and may travel without being liable to injury.
 6. That one section may be conveniently connected to the next.
 7. That the positive and negative plates, lugs and strips are so situated that there is no undue risk of short-circuiting.
 8. That they can be easily put in and taken out of their pots.
 9. That the plates can be easily examined.
- All these points and many others have already been*

discussed, and, therefore, to enter more fully into them would be simply to recapitulate.

It is often, desirable after a section has been in work for some time, to remove one or two plates and submit each one to a careful survey with a magnifying-glass to see if there is any tendency for the plate to crack or break; also to break up the plate and observe the appearance of the fracture, which will serve as a guide to ascertain how the formation extends from the surface towards the interior, or *vice versa*.

It is well known that thick positive plates possess practically no advantage over thin ones, although the former carry more paste. When a positive plate is charged, let it be supposed that the whole of the paste is in the peroxide state; then, on discharging, the surface first becomes sulphated, expanding during the process. In a short time this continued process of expansion, from the surface inwards, at last renders it impossible for the electrolyte to penetrate to the interior, or only in a very small degree.

The fair conclusion is that, if the paste be mixed with some other substance, so as to alter the mechanical structure by permitting the expansion to take place, and at the same time allow liquid to pass, the thicker a plate is made the greater will be its storage capacity. Possibly sand, powdered coke, or other such material mixed with the paste would improve the plate; or some salt, which will dissolve out, still leaving the paste solid. Common salt, or soda, in small quantities, might produce the desired result.

CHAPTER VII.

SUMMARY.

ALWAYS charge the cells until they boil well. Never allow the battery to run down till its E.M.F. is below the average of two volts per cell. If this should occur when it is known that the charge is not low, an examination of every cell should be made. The acidometers in the cells give an approximate idea of the state of the charge, if they are intelligently observed. Examine the plates every few days, by noticing their colour and other characteristics. No current-meter is of service to measure the charge remaining in the accumulator, since this instrument takes no account of the leakage which occurs before reaching it, nor of local action. As soon as only 25 per cent. of the total charge remains in the cells, the E. M. F. rapidly falls on further discharge. Precautions should be taken against too large a current flowing when charging is commenced, by inserting a resistance, or by means of an automatic governor; also, provision must be made against lamps being injured when they are turned on during charging hours, or the *moment* charging is completed. The instant any fault

is noticed it should be remedied at once, and any dead cell cut out immediately. Do not charge longer than necessary, but see that all the cells boil well; if any are much behind, ascertain if there is any obvious cause for this. Half an hour to an hour overcharging is advisable. Occasionally examine the insulation. Observe that the liquid in the cells does not become warm during the charging. All measuring apparatus should be compared with standard instruments periodically, so as to avoid falling into errors which may prove destructive to the plates. Feel all connections and switches every now and then, to see if they become warm.

Do not take advice for a remedy from the first person who gives it, before receiving an assurance from some competent authority that there is value in the recommendation. Amateurs often act in the former way, and generally the result is that a heavy penalty has to be paid, but, unfortunately, not by the individual who caused the mischief. Possessors of an accumulator should not at any time spare money in sending for competent persons to set any fault right, for an apparently trifling matter becomes very serious in a short time, and by the course suggested much good money is saved and vexation avoided. Above all, it must be remembered that no rules unmixed with brains are of the least service.

It is within the author's knowledge, as one result of the publication of this little book, (imperfect as it must necessarily be, with the changes which take place from day to day,) that a very large number of installations have been erected. On the other hand, a few cases have been brought to the notice of the writer where persons intending to use the electric light have been frightened

out of the attempt after perusing these pages; because they have brought themselves to believe that the trouble incurred by its adoption will prove greater than the advantage. He therefore wishes to address a few words to such timid readers.

The object of this work is twofold: firstly, to give a general survey of the subject, it being always presumed that his readers have already acquired a certain amount of technical knowledge; secondly, to cite, as far as possible, every conceivable case of failure and to state the remedy. It might, therefore, appear that the whole subject is beset with failure and has no elements of success. It is clear that a remedy for a failure is the very thing that experts seek. No book would be complete that did not deal with these points, and up to the moment of writing there seems to be no work treating of these matters in particular.

The present book has produced a large correspondence, chiefly relating to failures and accidents. Much gratitude is felt by the author for the information these letters convey. Even though a particular difficulty may be exceedingly rare, still it was considered worth while to report respecting it, and to recommend a remedy for the benefit of other persons.

Let the nervous reader imagine that the author, instead of writing about electricity, had published a book describing the various processes that an individual goes through, from, say, the moment he gets out of bed in the morning to his sitting down at breakfast; the pages that such a description would fill would be tenfold the number occupied in the present work. Let every little mishap that might occur during the *process* of washing and of dressing be set forth, as well

as the remedy. There would naturally be included in an account of that kind such possibilities as a tooth-brush bristle finding its way into the throat and producing inflammation, which might lead to serious consequences; and even such trifles would have to be mentioned as the stitching in clothing coming undone and the necessity of putting it to rights again. With such a deterrent picture before him, he must decidedly elect either to remain in bed for the rest of his natural life, or to dispense with clothing and the duties of the toilet altogether.

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